Lysack, W. 1980

1979 Lake Winnipeg Fish Stock Assessment Program

MANITOBA
DEPARTMENT OF NATURAL RESOURCES

MS Report No. 80-30

89-00696/

Lysack, W. 1980.

1979 Lake Winnipeg fish stock assessment program. Manitoba Department of Natural Resources, Research MS Rep. No. 80-30, 118pp.

ABSTRACT

This report presents the results of the 1979 Lake Winnipeg fish stock assessment program. Maturity rates of northern and southern walleye females were not significantly different. Maturity rates of northern and southern sauger females were not significantly different. The mean weighted ages of onset of sexual maturity of saugers and walleyes were younger in the south basin than in the north basin.

Both experimental and commercial catch curves of walleyes and saugers were generally convex in the north and concave in the south basin. This trend was amplified during the fall fishery. The experimental mortality rates of walleyes were not significantly different between the north and south basins. The experimental mortality rate of saugers was highest in the south basin and lowest in the north basin.

Growth of northern saugers, walleyes and whitefish was positively allometric while growth of southern walleyes and saugers was negatively allometric. Whitefish growth was positively allometric. Asymptotic sizes of northern, channel and southern saugers were 402, 361 and 301 mm, respectively. Asymptotic size of whitefish was 938 mm. Asymptotic

size of northern walleye could not be estimated since the Walford plot did not cross the agreement line. Asymptotic size of southern walleyes was 511 mm. The instantaneous growth rate of saugers was lowest in the north basin, intermediate in the channel and highest in the south basin using both exponential and von Bertalanffy growth models. Southern walleyes also grew faster than northern walleyes.

Net selectivity of experimental gangs for sauger and walleye ages was highest in the north basin and lowest in the south basin. Small meshes caught more numbers of saugers in the north basin. Larger meshes caught larger saugers in the north basin than they did in the south basin. Frequencies of immature saugers declined with increasing mesh size in the north basin. In the channel and south basin, frequencies of immature saugers were not related to mesh size. Frequencies of immature saugers caught in the channel and south basin were at least five times greater than in the north basin. Mean weights of northern walleyes increased faster with increasing mesh size than southern walleyes. The mean biomass mesh^{-1} of southern walleyes was equal to or greater than that of northern walleyes in smaller meshes but decreased faster with increasing mesh size than northern walleye biomass. Frequencies of immature northern walleyes decreased rapidly with increasing mesh size while frequencies of immature southern walleyes increased with increasing mesh size. Mean lengths and weights of whitefish increased rapidly with increasing mesh size. The mean biomass mesh^{-1} of whitefish was greatest in the 3.75 inch

mesh. Frequencies of immature whitefish decreased regularly with increasing mesh size.

Mean ages of commercially caught saugers and walleyes were generally lower in the south basin than in the north basin during the summer and fall commercial seasons. Walleye survival rates were not significantly different between the north and south basins during the summer commercial season and during the fall commercial season. Annual mortality rates of walleyes decreased from summer to autumn. Differences between north and south sauger survival rates were not significant in summer, but towards autumn, southern sauger mortality became significantly higher than its northern counterpart. Differences in whitefish survival rates between summer and fall fisheries were not significant.

Abrasov's (1967) t index was negative for all species in all basins except for the summer and fall south sauger fisheries and the whitefish fishery.

TABLE OF CONTENTS

	Page
ABSTRACT	i
INTRODUCTION	1
METHODS AND MATERIALS	3
Experimental sampling	3
Commercial sampling	5
Calculations	6
RESULTS	7
Experimental sampling	7
Maturity regimes	9
Age compositions, catch curves and mortality rates	16
Growth regimes	21
Differences between scale ages and otolith ages	46
Net selectivity	46
Mesh size effects	57
Commercial sampling	74
DISCUSSION	89
Experimental sampling	89
Species proportions	89
Maturity regimes	90
Age compositions, catch curves and mortality rates	92
Growth regimes	93
Net selectivity	94

Page

Mesh size effects 95

Summary 96

RECOMMENDATIONS 99

ACKNOWLEDGMENTS 101

LITERATURE CITED 102

APPENDIX A 107

APPENDIX B 110

APPENDIX C 112

LIST OF TABLES

Table		Page
1.	Maturity schedules of north end (gangs 1 - 18) walleyes	10
2.	Maturity schedules of north end (gangs 1 - 18) saugers	10
3.	Maturity schedules of north end (gangs 1 - 18) whitefish	10
4.	Maturity schedules of south end (gangs 27 - 38) saugers	11
5.	Maturity schedules of south end (gangs 27 - 38) walleyes	12
6.	Linear equations describing proportional rates of maturity with respect to age of Lake Winnipeg saugers, walleye and whitefish	13
7.	Results of covariance analyses of maturity curves.	14
8.	Linear equations describing proportional rates of maturity with respect to age of Lake Winnipeg saugers, walleyes and whitefish	15
9.	Mean weighted ages of onset of sexual maturity . .	17
10.	Comparison of northern and southern female walleye and sauger maturity curves. Southern curves are composed of mature and developing female data . .	18
11.	Mortality and survival rates estimated by regression and the Robson-Chapman method	24

Table Page

12. Age-specific mean fork lengths and mean weights of saugers from the three major areas of Lake Winnipeg, 1979 27
13. Age-specific mean fork lengths and mean weights of northern Lake Winnipeg whitefish, 1979 28
14. Age-specific mean fork lengths and mean weights of walleyes from northern and southern Lake Winnipeg, 1979 29
15. Length-weight relationships of saugers, whitefish and walleyes from the three major areas of Lake Winnipeg 30
16. Linear equations of Walford plots fitted by least squares regression 36
17. Correlation coefficients of untransformed and transformed growth curves 42
18. Fitted growth curves of Lake Winnipeg stocks, 1979 . 47
19. Age compositions of commercially caught species from the three major areas of Lake Winnipeg during the summer and fall fishing seasons 75
20. Mortality rates of commercially caught species from the three major areas of Lake Winnipeg during the summer and fall fishing seasons 73
21. Abrasov's (1967) t indices for walleyes, saugers and whitefish from the three major area of Lake Winnipeg 88

Table | Page

22. Relationships of minimum mesh sizes and various population parameters of saugers within the three major areas of Lake Winnipeg 97

23. Relationships of minimum mesh sizes and various population parameters of walleyes within the northern and southern areas of Lake Winnipeg . . . 98

LIST OF FIGURES

Figures		Page
1.	Locations of sampling stations on Lake Winnipeg. Numbers denote chronological order of gang sets. Area A - F are management areas of the summer fishery. Gangs 25 & 26 were set in an area where commercial fisheries are prohibited	4
2.	Species composition from experimental gillnets set in Lake Winnipeg in 1979. A - north end, B - channel area, C - south end	8
3.	Age compositions of northern (A) and southern (B) walleye stocks in Lake Winnipeg, 1979	19
4.	Age composition of Lake Winnipeg whitefish stocks, 1979.	20
5.	Age compositions of southern (A), channel (B) and northern (C) sauger stocks in Lake Winnipeg, 1979	22
6.	Catch curves of northern and southern walleye stocks in Lake Winnipeg, 1979	23
7.	Catch curve of the northern Lake Winnipeg whitefish stocks, 1979	25
8.	Catch curves of northern and southern sauger stocks in Lake Winnipeg, 1979	26
9.	Length-weight relationships of northern, channel and southern saugers from Lake Winnipeg, 1979 . .	31
10.	Length-weight relationship of Lake Winnipeg whitefish, 1979	32

Figure Page

11. Length-weight relationships of northern and southern walleyes from Lake Winnipeg, 1979 33
12. Walford plots of northern, channel and southern saugers from Lake Winnipeg, 1979 35
13. Walford plot of whitefish mean lengths 37
14. Walford plots of northern (A) and southern (B) walleye mean lengths. Lengths denoted by open circles were omitted from the analysis 38
15. Temporal changes in mean lengths of northern channel and southern saugers from Lake Winnipeg, 1979. The last four ages of northern saugers were determined from otoliths. 39
16. Temporal changes in mean lengths of whitefish from Lake Winnipeg, 1979. 40
17. Temporal changes in mean lengths of northern and southern walleyes from Lake Winnipeg, 1979 41
18. Linear regressions of $L_\infty - l_t$ versus t for northern, channel and southern Lake Winnipeg saugers, 1979 . 43
19. Linear regression of $L_\infty - l_t$ versus t for Lake Winnipeg whitefish, 1979 44
20. Linear regression of $L_\infty - l_t$ versus t for southern Lake Winnipeg walleyes, 1979 45
21. Von Bertalanffy growth curves of northern, channel and southern saugers from Lake Winnipeg, 1979 . . 48
22. Von Bertalanffy growth curve of southern Lake Winnipeg walleyes, 1979 49

Figure | Page

23. Von Bertalanffy growth curve of whitefish from Lake Winnipeg, 1979 50

24. Differences between scale ages and mean otolith ages of saugers from the northern, channel and southern areas of Lake Winnipeg. Vertical bars are 95% confidence intervals about the age-specific mean otolith ages. The slope of the agreement line is 1 51

25. Net selectivity with respect to ages of northern saugers 52

26. Net selectivity with respect to ages of channel saugers 53

27. Net selectivity with respect to ages of southern saugers 54

28. Net selectivity with respect to ages of northern walleyes 55

29. Net selectivity with respect to ages of southern walleyes 56

30. Net selectivity with respect to ages of northern whitefish 58

31. Effects of mesh size on the mean numbers of saugers mesh^{-1} in the three major areas of Lake Winnipeg. 59

32. The relationship of mean lengths of saugers and mesh sizes in the three major areas of Lake Winnipeg 60

Figure Page

33. The relationship of mean weights of saugers and mesh sizes in the three major areas of Lake Winnipeg 61

34. Changes in the mean biomass of saugers per mesh over a range of meshes in the three major areas of Lake Winnipeg 62

35. Changes in frequencies of immature saugers in relation to mesh size in the three major areas of Lake Winnipeg 64

36. Changes in mean numbers (● ■) and mean weights (▲ ▼) of northern and southern walleyes in relation to mesh size 65

37. Changes in mean lengths of northern and southern walleyes in relation to mesh size 66

38. Changes in mean biomass of walleyes per mesh in relation to mesh size in the north and south basins 67

39. Changes in frequencies of immature walleyes in relation to mesh size in the northern and southern basins 68

40. Changes in mean lengths of northern whitefish in relation to mesh size 69

41. Changes in mean weights of northern whitefish in relation to mesh size 70

Figure Page

42. Changes in mean biomass of whitefish per mesh in relation to mesh size 71
43. Changes in frequencies of immature whitefish in relation to mesh size 72
44. Age compositions of commercially caught northern (A), channel (B) and southern (C) saugers from Lake Winnipeg, summer 1979 77
45. Age compositions of commercially caught saugers from the northern (A), channel (B) and southern (C) areas of Lake Winnipeg, autumn 1979 78
46. Age compositions of commercially caught walleyes from the northern (A), channel (B) and southern (C) areas of Lake Winnipeg, summer 1979 79
47. Age compositions of commercially caught walleyes from northern (A), channel (B) and southern (C) areas of Lake Winnipeg, fall 1979 80
48. Age compositions of commercially caught whitefish from the northern (A) and channel (B) areas of Lake Winnipeg, summer 1979 81
49. Summer catch curves of commercially caught saugers from the northern, channel and southern areas of Lake Winnipeg, 1979 82
50. Autumn catch curves of commercially caught saugers from the northern, channel and southern areas of Lake Winnipeg, 1979 83

Figure Page

51. Summer catch curves of commercially caught walleyes from the northern, channel and southern areas of Lake Winnipeg, 1979 84

52. Autumn catch curves of commercially caught walleyes from the northern, channel and southern areas of Lake Winnipeg, 1979 85

53. Summer and fall 1979 catch curves of commercially caught whitefish from Lake Winnipeg 86

INTRODUCTION

Lake Winnipeg is the site of Manitoba's most important fishery. The three most important fish species commercially caught in Lake Winnipeg are saugers, *Stizostedion canadense*, walleyes, *Stizostedion vitreum*, and whitefish, *Coregonus clupeaformis*. Other fish that have been or are being commercially harvested to a lesser extent are: perch, *Perca fluviatilis*, pike, *Esox lucius*, tullibee, *Coregonus artedii*, goldeye, *Hiodon alosoides*, lake sturgeon, *Acipenser fulvescens*, longnose suckers, *Catostomus catostomus*, white suckers, *Catostomus commersoni*, rock bass, *Ambloplites rupestris*, white bass, *Morone chrysops*, carp, *Cyprinus carpio*, burbot, *Lota lota*, freshwater drum, *Aplodinotus grunniens*, and various catfish and bullheads, *Ictalurus sp.*

The major whitefish fishery on Lake Winnipeg occurs on the north end of the lake from early June to early August. The sauger and walleye fisheries occur primarily on the south end of the lake and in isolated areas along the northeastern and northwestern shores. Saugers and walleyes are harvested during the summer and fall seasons and to a lesser extent in winter. Lake Winnipeg fisheries have been described in detail by Kennedy (1954), Doan (1959), Hewson (1959, 1960) and Davidoff *et al.* (1973). Lake Winnipeg fishery management regulations and management areas are recorded annually in the Manitoba Gazette (Province of Manitoba).

Many research projects dealing with diverse topics have been conducted on Lake Winnipeg since 1930. Early reports

were generalized descriptions of fishery activities (Bajkov 1930, Grant 1938, Hewson 1951), fish parasites (Bajkov 1933, Kennedy 1951, Keleher 1952), plankton (Bajkov 1935), benthos (Neave 1932, 1933; Arnason 1951) and species compositions and distributions (Hinks 1943, Keleher and Kooyman 1957). Later reports routinely dealt with the status of exploited fish stocks (Kooyman 1952, Doan 1959, Hewson 1959, 1960; Rybicki and Doan 1966), mesh size experiments (Kooyman 1955, Hewson 1957) and mark-recapture experiments (Hewson 1953, Kennedy 1954, Rybicki 1961, 1962). Recently, more specialized reports deal with mercury and pesticide pollution (Bligh 1970, 1972; Kennedy 1972, Reinke *et al.* 1972 Scott and Armstrong 1972), limnology (Kushner 1971, Evans and Stockner 1972, Kristofferson *et al.* 1975, Brunskill *et al.* 1979) and advances in ecological monitoring (Green 1971, 1972).

A review of former studies of Lake Winnipeg's exploited fish stocks presents a diverse array of different approaches and techniques of sampling and analyses (Kennedy 1954, Hewson 1959, 1969; Davidoff *et al.* 1973, Howard 1974). This methodological diversity confounds comparisons of results when one attempts to analyze long term changes in the population dynamics of Lake Winnipeg's exploited fish stocks.

The objectives of this study were: 1) to determine fish species compositions in various commercial fishing zones of Lake Winnipeg, 2) to determine sex ratios and maturity schedules of walleyes, saugers and whitefish in various management areas, 3) to compare scale and otolith ages of saugers from various areas of the lake, 4) to determine growth and mortality rates of saugers,

walleyes and whitefish, 5) to attempt to relate population characteristics to commercial fishing activities in major areas of Lake Winnipeg and 6) to discuss management implications of this study.

This study was restricted to the ice-free season on Lake Winnipeg. Only one or two gangs of gillnets were set once at each sampling site.

METHODS AND MATERIALS

Experimental sampling

Twenty seven stations were sampled on Lake Winnipeg during the summer and autumn of 1979 (Fig. 1). One or two gangs of gillnets were set once at each station for one overnight period (16 - 18 hours).

For sets 1 to 26 (Fig. 1), the gillnet gang was composed of the following meshes: 7.62 cm (3 in), 8.26 cm (3.25 in), 9.53 cm (3.75 in), 10.80 cm (4.25 in), 12.70 cm (5 in) and 13.34 cm (5.25 in).

For sets 27 to 38 (Fig. 1), the gillnet gang was composed of the following meshes: 7.62 cm (3 in), 8.26 cm (3.25 in), 8.89 cm (3.5 in), 9.53 cm (3.75 in), 10.16 cm (4 in), and 10.80 cm (4.25 in). Each net in the gang was 45.72 m (50 yd) long and approximately 1.83 m (2 yd) deep.

Walleyes, saugers and whitefish caught in the gangs were processed as follows: The fork length of each fish was measured to the nearest 2 mm. Each fish was weighed to the nearest 20 gm on a Chatillon spring scale (Chatillon, Mississauga, Ontario). Six to ten scales were collected from the left side of each fish.

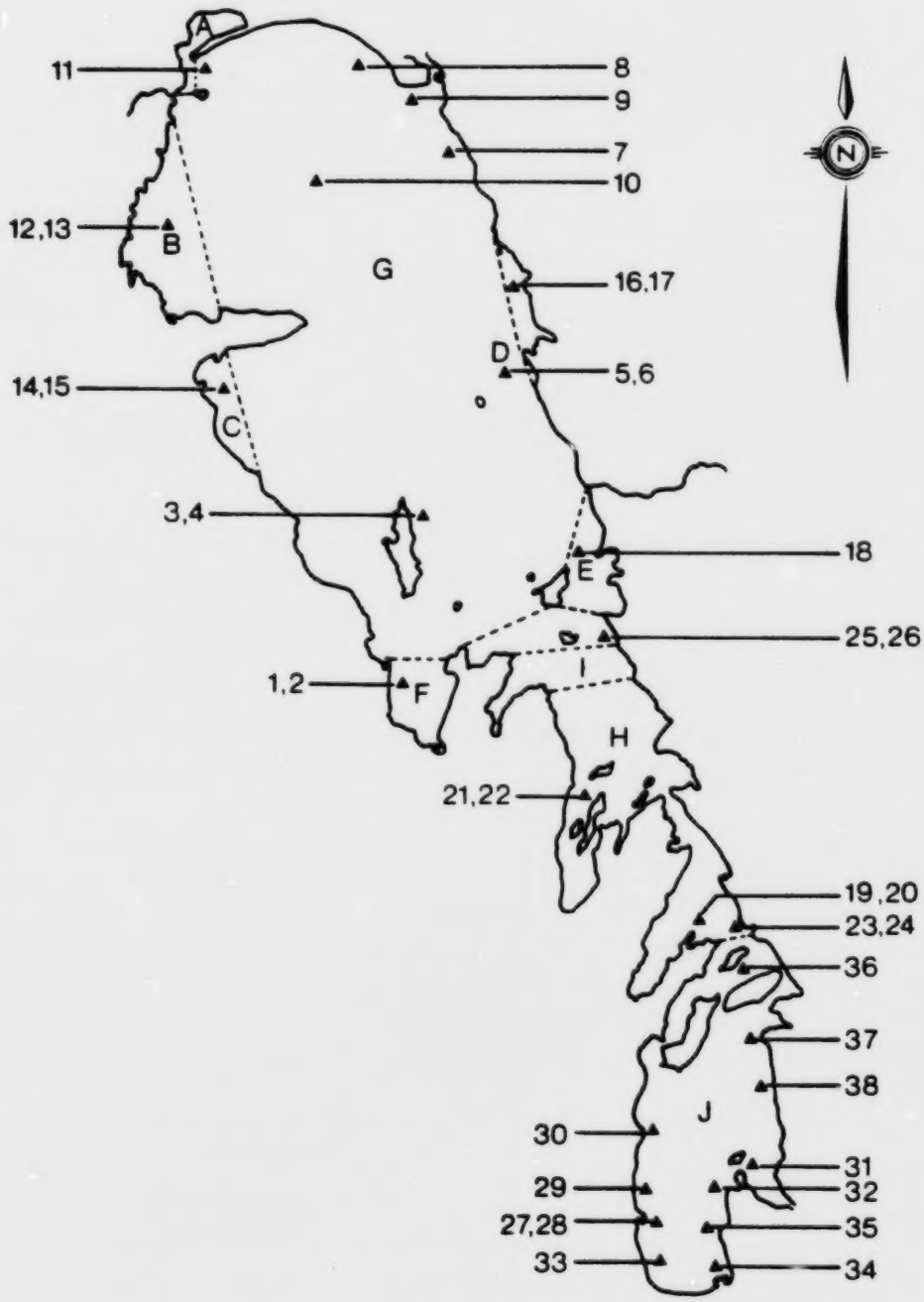

Fig. 1. Locations of sampling stations on Lake Winnipeg. Numbers denote chronological order of gang sets. Area A - F are management areas of the summer fishery. Gangs 25 & 26 were set in an area where commercial fisheries are prohibited.

Scales were removed above the lateral line below the anterior edge of the dorsal fin. Otoliths were collected from 589 saugers caught in the north end, channel and south end of Lake Winnipeg. The sex and state of maturity of each fish was visually determined by examining gonads. Fish from sets 1 to 26 (Fig. 1) were classified as being either immature or mature. Fish from sets 27 to 38 were classified as being either immature or developing or mature. The above sexual maturity categories were recently described by Olynyk (unpublished report).

The mesh size that caught each walleye, sauger and whitefish was recorded. Numbers of other fish of non-commercial species per gang were recorded.

A microfiche reader (Data View, model LF 1015) was used to analyze scales and otolith sections. Scales were examined at 24X and 48X. Otoliths were embedded in epoxy. Two 0.5 mm sections were cut through the nucleus of each otolith using an Isomet low-speed saw (model 11-1180, Buehler Ltd., Evanston, Ill.). Otolith sections were cleaned in absolute ethanol and were mounted on glass slides with Diatex, a liquid glass medium. Otolith sections were examined at 72X.

Commercial sampling

Commercial catches were sampled during the summer and fall commercial fishing seasons. Samples were collected from fishermen's catches at Warren's Landing, Grand Rapids, Gull Bay, Sturgeon Bay, George Island, Poplar and Big Black Rivers, Berens River, Matheson Island, Gimli and Selkirk. Walleyes, saugers and whitefish were randomly selected from catches and were processed in the same manner as experimentally caught fish. Sex and state

of maturity of each commercially caught fish could not be determined since these fish were dressed. Commercial data were pooled with respect to the three major areas of Lake Winnipeg: northern pool - areas A - G, channel pool areas H and I, and southern pool area J (Fig. 1).

Calculations

Routine statistical analyses were performed according to Snedecor and Cochran (1967). Total mortality rates were calculated according to Robson and Chapman (1961). For comparative purposes, data from the three major areas of Lake Winnipeg were pooled as follows: gangs 1 - 18 comprised the northern pool, gangs 19 - 26 comprised the channel pool and gangs 27 - 38 comprised the southern pool.

The description of the frequency of mature walleyes, saugers and whitefish at various ages was based on a logistic model:

$$Y_x = \frac{k}{1 + e^{-b(x - x_o)}}$$

where Y_x = frequency of mature fish among all fish aged x

k = frequency of mature fish among the oldest age groups

x_o = age at inflection point

b = slope

It was assumed that $k = 100\%$. To facilitate fitting a regression by least squares, the data were transformed as follows:

$$-\log_e \left(\frac{k - y}{y} + 1\right) = -bX_o + bX$$

The mean weighted age of onset of sexual maturity was calculated as follows:

$$Z = \frac{A_1K_1 + A_2 (K_2 - K_1) + A_3 (K_3 - K_2) + \ldots + A_n (K_n - K_{n-1})}{K_1 + (K_2 - K_1) + (K_3 - K_2) + \ldots + (K_n - K_{n-1})}$$

where A = age (years)

K_n = % of mature fish in the n^{th} age class. This is a corrected version of Abrasov's (1967) original formula.

Mean biomass per mesh in each major area of the lake was calculated as follows:

$$\text{Biomass} = \frac{\Sigma w}{n}$$

where Σw = sum of all the individual weights of fish of a species caught in a specific mesh in all the gangs set in each major area.

n = number of gangs set in each major area.

This estimate of biomass is considered to represent the more usual product of numbers and mean weight.

RESULTS

Experimental sampling

Species proportions

The relative proportions of various species gillnetted during 1979 (Fig. 2, Appendix A) indicate the following:

1. Whitefish are substantially more numerous in the north end than in the channel and southern areas of Lake Winnipeg.
2. Proportions of saugers were higher than proportions of walleyes in the north and channel areas. In the south, the proportion of walleyes was about equal to the proportion of saugers.
3. Freshwater drum and all the sucker species are among the dominant species present in the channel area. Drum and northern redhorse

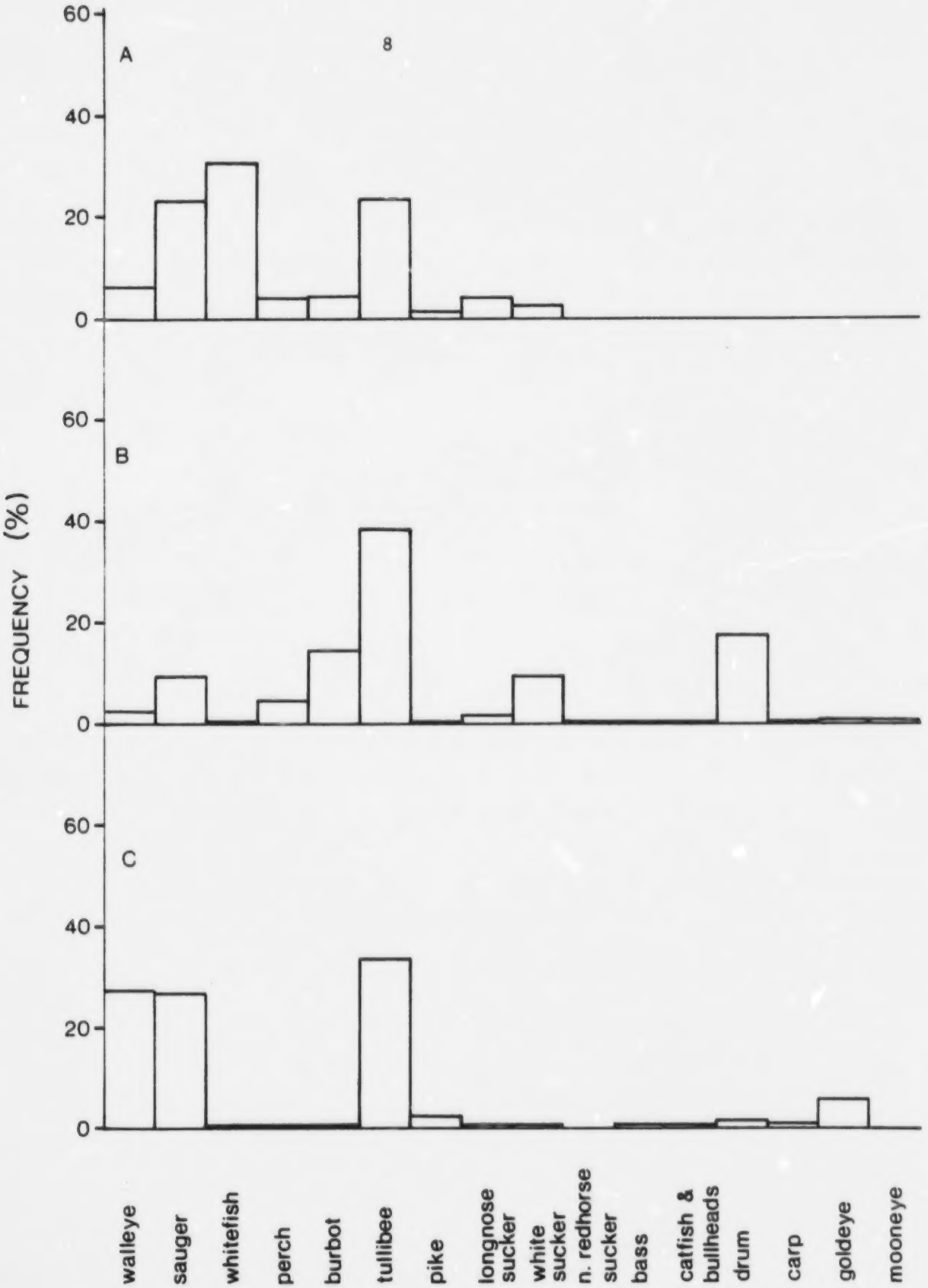

Fig. 2. Species composition from experimental gillnets set in Lake Winnipeg in 1979. A - north end, B - channel area, C - south end.

suckers were not present in the north end.

4. Goldeyes were relatively more abundant in the south end than in the channel. Goldeyes were not present in the north end of the lake.
5. Perch and burbot were relatively more abundant in the north and channel areas than in the south end.
6. In terms of numbers, tullibees dominated the species composition in the channel and south end.
7. Commercially undesirable species were dominant in the channel, were less dominant in the south and were rarely present in the north end.

Maturity regimes

Analyses of sex-specific maturity schedules of walleyes, saugers and whitefish from the northern and southern areas of Lake Winnipeg (Tables 1 - 5) showed non-significant relationships of maturity and age for northern sauger males, northern whitefish females and southern walleye males (Table 6). Male-female comparisons of sauger, walleye and whitefish maturity curves from northern Lake Winnipeg showed no difference between maturity rates (Table 7). In the south end, sauger females mature faster than sauger males (Table 7). No significant differences in maturity rates exist between northern and southern sauger and walleye males and females (Table 7).

Since sex does not affect maturity rates of northern and southern walleyes and northern saugers, these data were combined to derive maturity curves which included both sexes (Table 8). Analysis of covariance showed that no difference exists between the maturity rates of northern and southern saugers ($F = 0.093$, 1 and 7 d.f., $P = 0.05$). The maturity rates of northern and southern walleyes were significantly different ($F = 12.65$, 1 and 8 d.f., $P = 0.05$).

Table 1. Maturity schedules of north end (gangs 1 - 18) walleyes.

Age (yrs)	Males*			Females*		
	no. immature	no. mature	% mature	no. immature	no. mature	% mature
3	2	0	0	3	0	0
4	29	4	12.12	54	3	5.26
5	23	4	14.81	69	8	10.39
6	6	4	40.00	41	16	28.07
7	2	10	83.33	16	16	50.00
8	0	3	100.00	5	7	58.33
9	0	1	100.00	0	2	100.00

*Gangs 1 - 18 caught 88 male walleyes and 240 female walleyes. Overall sex ratio is 0.367 male : 1 female.

Table 2. Maturity schedules of north end (gangs 1 - 18) saugers.

Age (yrs)	Males*			Females*		
	no. immature	no. mature	% mature	no. immature	no. mature	% mature
3	0	0	0	0	0	0
4	5	1	20.00	1	1	50.00
5	1	8	88.89	7	24	77.42
6	3	32	91.43	10	108	91.53
7	4	68	94.44	7	144	95.36
8	1	82	98.80	5	168	97.11
9	0	46	100.00	5	127	96.21
10				2	48	96.00
11				1	32	96.97
12				0	17	100.00

*Gangs 1 - 18 caught 302 male saugers and 745 female saugers. Overall sex ratio is 0.405 male : 1 female.

Table 3. Maturity schedules of north end (gangs 1 - 18) whitefish.

Age (yrs)	Males*			Females*		
	no. immature	no. mature	% mature	no. immature	no. mature	% mature
2	0	0	0	0	0	0
3	10	1	9.09	5	1	16.67
4	73	34	31.78	45	72	61.54
5	97	120	55.30	40	255	86.44
6	58	97	62.58	17	193	91.91
7	25	31	55.36	3	61	95.31
8	2	7	77.78	0	28	100.00
9	1	0	-	0	4	100.00
10	0	0	-	0	0	100.00
11	0	1	100.00	0	1	100.00

*Gangs 1 - 18 caught 557 male whitefish and 726 female whitefish. Overall sex ratio is 0.767 male : 1 female.

Table 4. Maturity schedules of south end (gangs 27 - 38) saugers.

Age (yrs)	Males*					Females*				
	no. immature	no. developing	no. mature	% developing	% mature	no. immature	no. developing	no. mature	% developing	% mature
2	0	6	0	100.00	0	0	0	0	0	0
3	0	33	11	75.00	25.00	7	11	5	47.83	21.74
4	0	147	44	76.96	23.04	17	59	15	64.84	16.48
5	0	160	10	94.12	5.88	3	98	8	89.91	7.34
6	0	23	1	95.83	4.17	0	17	0	100.00	0
7	0	1	0	100.00	0	0	1	0	100.00	0
8	0	1	0	100.00	0	0	0	0	0	0

*Gangs 27 - 38 caught 437 male saugers and 241 female saugers. Overall sex ratio is 1.813 males: 1 female.

Table 5. Maturity schedules of south end (gangs 27 - 38) walleyes.

Age (yrs)	Males*					Females*				
	no. immature	no. developing	no. mature	% developing	% mature	no. immature	no. developing	no. mature	% developing	% mature
1	1	0	0	0	0	0	0	0	0	0
2	9	2	1	16.67	8.33	5	0	0	0	0
3	17	64	8	71.91	8.99	43	0	1	0	2.27
4	21	113	29	69.33	17.79	75	2	7	2.38	8.33
5	7	84	18	77.06	16.51	58	6	2	9.09	3.03
6	3	26	0	89.66	0	17	7	4	25.00	14.29
7	0	2	0	100.00	0	5	3	0	60.00	0
8	0	0	0	0	0	1	1	0	50.00	0
9	0	0	0	0	0	0	2	0	100.00	0

*Gangs 27 - 38 caught 405 male walleyes and 239 female walleyes. Overall sex ratio is 1.694 males: 1 female.

Table 6. Linear equations describing proportional rates of maturity with respect to age of Lake Winnipeg saugers, walleye and whitefish.

Lake area	Species	Sex	Linear equation* $-\log_e(\frac{k-y}{y}+1) = -bX_o + bX$	Inflection point (years)	Correlation coefficient	Test F value and d.f.	Significance (P = 0.05)
North end (gangs 1-18)	sauger	male	Y = -2.330 + 0.326X	7.147	0.746	3.76(1,4)	non-significant
		female	Y = -0.678 + 0.070X	9.686	0.742	7.36(1,7)	significant
	walleye	male	Y = -5.007 + 0.678X	7.385	0.974	36.29(1,3)	significant
		female	Y = -5.372 + 0.638X	8.420	0.975	56.59(1,4)	significant
	whitefish	male	Y = -2.876 + 0.358X	8.034	0.850	10.41(1,5)	significant
		female	Y = -2.455 + 0.389X	6.311	0.835	6.89(1,4)	non-significant
South end (gangs 27-38)	sauger	male	Y = -0.585 + 0.094X	6.223	0.934	13.60(1,3)	significant
		female	Y = -1.688 + 0.316X	5.342	1.000	2336.31(1,2)	significant
	walleye	male	Y = -1.945 + 0.343X	5.671	0.788	4.91(1,4)	non-significant
		female	Y = -6.531 + 0.798X	8.184	0.943	24.05(1,4)	significant

*see text for derivation.

Table 7. Results of covariance analyses of maturity curves.

Comparison	Slopes test F value and d.f.	Slope significance (P = 0.05)
northern sauger males vs. northern sauger females	4.69(1,9)	non-significant
northern walleye males vs. northern walleye females	0.076(1,5)	non-significant
northern whitefish males vs. northern whitefish females	0.028(1,7)	non-significant
southern sauger males vs. southern sauger females	32.29(1,3)	significant
southern walleye males vs. southern walleye females	4.09(1,6)	non-significant
northern sauger males vs. southern sauger males	1.05(1,5)	non-significant
northern sauger females vs. southern sauger females	4.80(1,7)	non-significant
northern walleye males vs. southern walleye males	2.20(1,5)	non-significant
northern walleye females vs. southern walleye females	0.75(1,6)	non-significant

Table 8. Linear equations describing proportional rates of maturity with respect to age of Lake Winnipeg saugers, walleyes and whitefish.

Lake area	Species	Linear equation	Inflection point (years)	Correlation coefficient	Test F value and d.f.	Significance (P = 0.05)
North end (gangs 1-18)	sauger	Y = 1.189 - 0.128X	9.29	0.663	4.71(1,7)	non-significant
	walleye	Y = 4.928 - 0.593X	8.31	0.976	59.78(1,4)	significant
	whitefish	Y = 2.107 - 0.257X	8.20	0.764	7.00(1,6)	significant
South end (gangs 27-38)	sauger	Y = 0.260 - 0.050X	5.20	1.0	2980.10(1,2)	significant
	walleye	Y = 1.265 - 0.107X	11.82	0.508	1.74(1,6)	non-significant

The mean weighted ages of onset of sexual maturity (Table 9) indicate that northern saugers and walleyes mature at a relatively slow rate. The mean age of maturity of southern saugers is 3.66 years less than that of northern saugers. Southern walleyes mature 2.46 years before northern walleyes (Table 9).

Since transformed maturity curves were non-significant for northern and southern walleye and sauger males (Table 6) and since the use of the developing category was considered to be subjective (Table 4, 5), the mature and developing categories were combined for southern walleye and sauger females. Slopes of the resulting curves were all significantly different from zero. Southern maturity curves were not significantly different from their northern counterparts (Table 10).

Age compositions, catch curves and mortality rates

Ages of northern walleyes ranged from 3 to 9 years with a mode of 5 years and a mean of 5.35 years. Ages of southern walleyes ranged from 1 to 9 years with a mode of 4 years and a mean of 4.16 years (Fig. 3). Both northern and southern walleye age compositions were leptokurtic and both contained three age classes that each comprised over 20% of the total catches.

. The distribution of whitefish ages was highly leptokurtic and positively skewed. Ages ranged from 2 to 14 years with a modal age of 5 years and a mean age of 5.41 years (Fig. 4).

Ages of southern saugers ranged from 2 to 8 years with modal and mean ages of 4 and 4.38 years, respectively. The southern sauger age distribution was highly leptokurtic.

Table 9. Mean weighted ages of onset of sexual maturity.

Lake area	Species	Mean age of maturity (years)
North end	sauger	6.44
	walleye	7.85
	whitefish	2.49
South end	sauger	2.78
	walleye	5.39

Table 10. Comparison of northern and southern female walleye and sauger maturity curves. Southern curves are composed of mature and developing female data.

Species	Lake area	Maturity equation	X_o (yrs)	Correlation coefficient	Test F value d.f., and significance at P = 0.05	Slopes test F value and d.f.
Walleye	North	Y = -5.372 + 0.638X	8.42	0.975	56.59(1,4) significant	0.129(1,7)
	South	Y = -4.983 + 0.581X	8.58	0.931	25.86(1,5) significant	
Sauger	North	Y = -0.678 + 0.070X	9.686	0.742	7.36(1,7) significant	0.749(1,7)
	South	Y = -0.867 + 0.167X	5.19	0.999	619.49(1,2) significant	

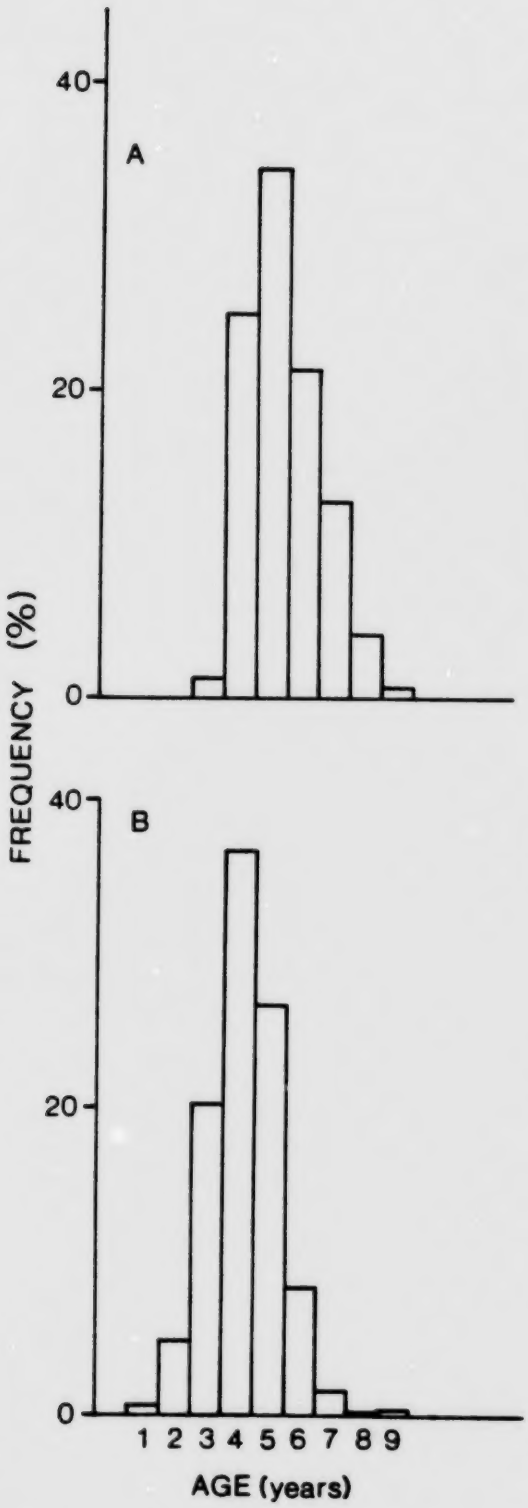

Fig. 3. Age compositions of northern (A) and southern (B) walleye stocks in Lake Winnipeg, 1979.

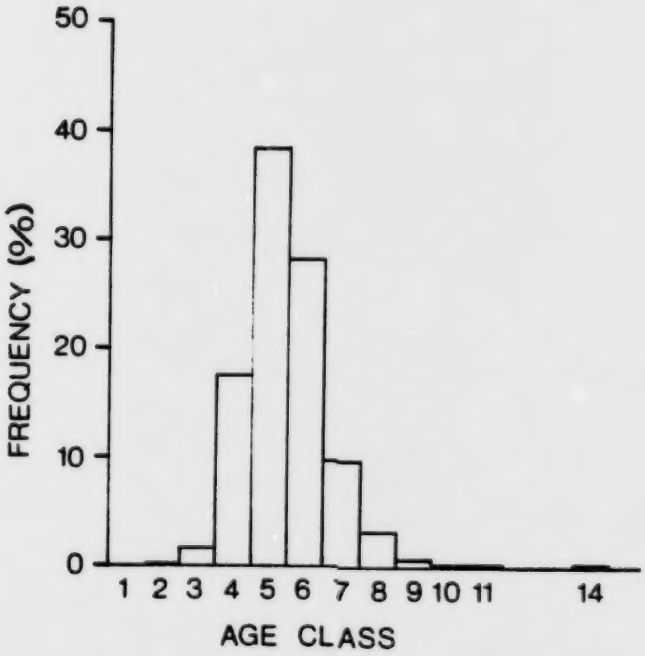

Fig. 4. Age composition of Lake Winnipeg whitefish stocks, 1979.

The northern sauger age distribution was relatively more platykurtic with a range of 4 to 14+ years and modal and mean ages of 8 years and 8.14 years, respectively. The age range of channel saugers (2 to 10 years) was intermediate to its northern and southern counterparts. The modal and mean ages of channel saugers were 5 years and 4.99 years, respectively (Fig. 5).

The northern walleye catch curve was slightly more convex than its southern counterpart (Fig. 6). Regression analysis of the right limbs of these curves produced estimates of the instantaneous total mortality rates that were not significantly different from each other or from the Robson-Chapman mortality rates (Table 11).

The whitefish catch curve was concave (Fig. 7). The whitefish mortality rates estimated by regression and the Robson-Chapman method were not significantly different (Table 11).

Robson-Chapman and regression estimates of sauger mortality rates (Fig. 8) were not significantly different within each major area but the northern rate was significantly lower than the southern rate (Table 11). The mortality rate of channel saugers was intermediate to its northern and southern counterparts.

Growth regimes

Age-specific mean lengths and weights of saugers (Table 12), whitefish (Table 13) and walleyes (Table 14) from the three major areas of Lake Winnipeg wree used to derive length-weight relationships (Table 15, Figs. 9 - 11). Covariance analysis of logtransformed sauger length-weight curves (Fig. 9) showed significant differences

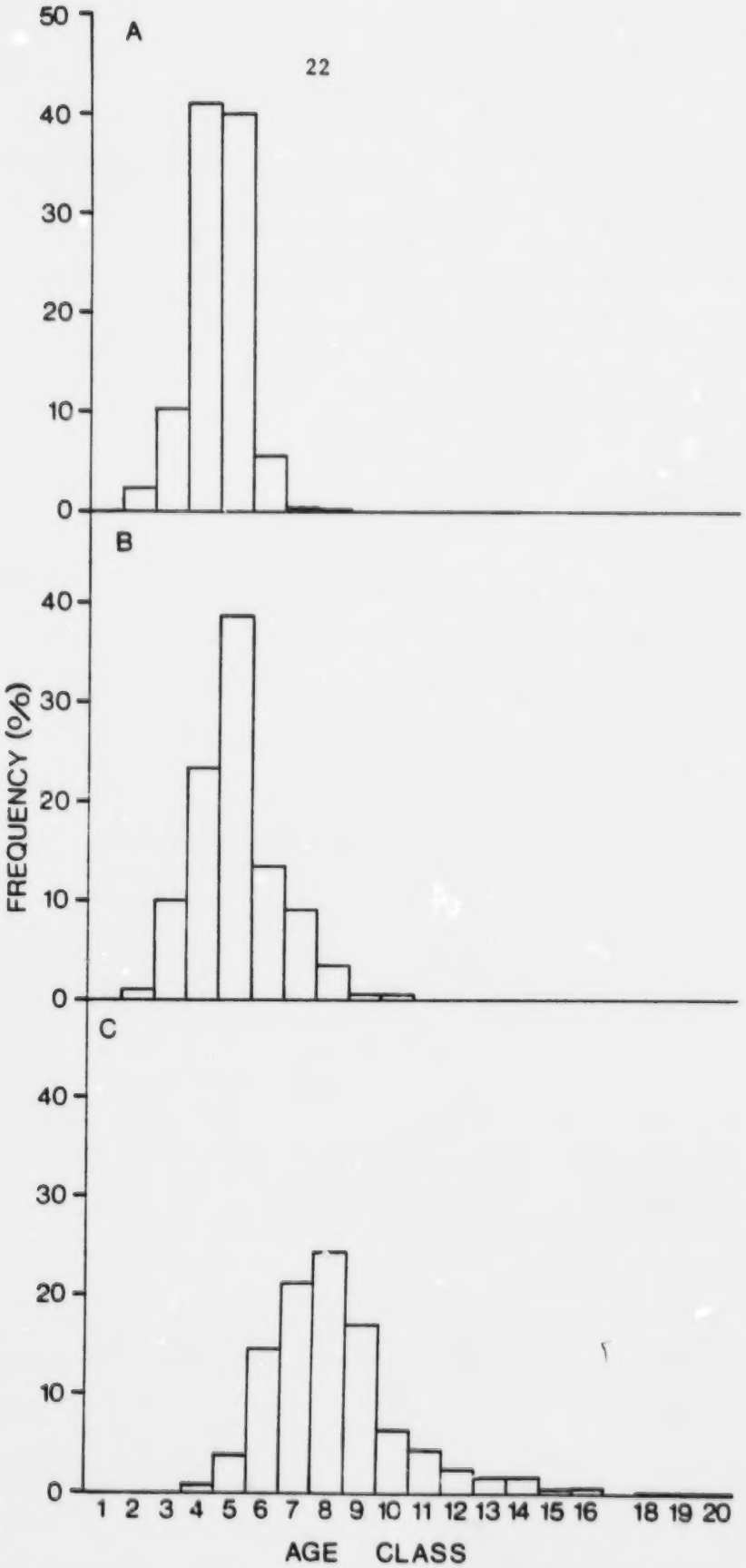

Fig. 5. Age compositions of southern (A), channel (B) and northern (C) sauger stocks in Lake Winnipeg, 1979.

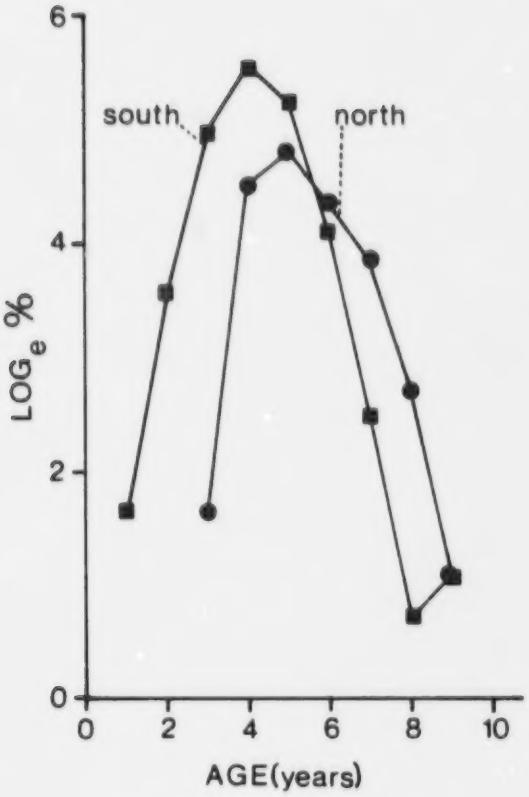

Fig. 6. Catch curves of northern and southern walleye stocks in Lake Winnipeg, 1979.

Table 11. Mortality and survival rates estimated by regression and the Robson-Chapman method.

Species	Area	Robson-Chapman			Regression		
		Z	A	S ± 2 S.E.	Z	A	S
Walleye	north	0.92	0.602	0.268 < 0.400 < 0.532	0.727	0.518	0.482
	south	1.30	0.728	0.114 < 0.273 < 0.402	1.203	0.699	0.301
Sauger	north	0.54	0.417	0.472 < 0.583 < 0.694	0.375	0.316	0.684
	channel	0.82	0.600	0.281 < 0.441 < 0.600	0.567	0.435	0.566
	south	2.07	0.874	0.034 < 0.126 < 0.218	2.244	0.891	0.109
Whitefish	north	1.14	0.680	0.200 < 0.320 < 0.440	1.094	0.664	0.336

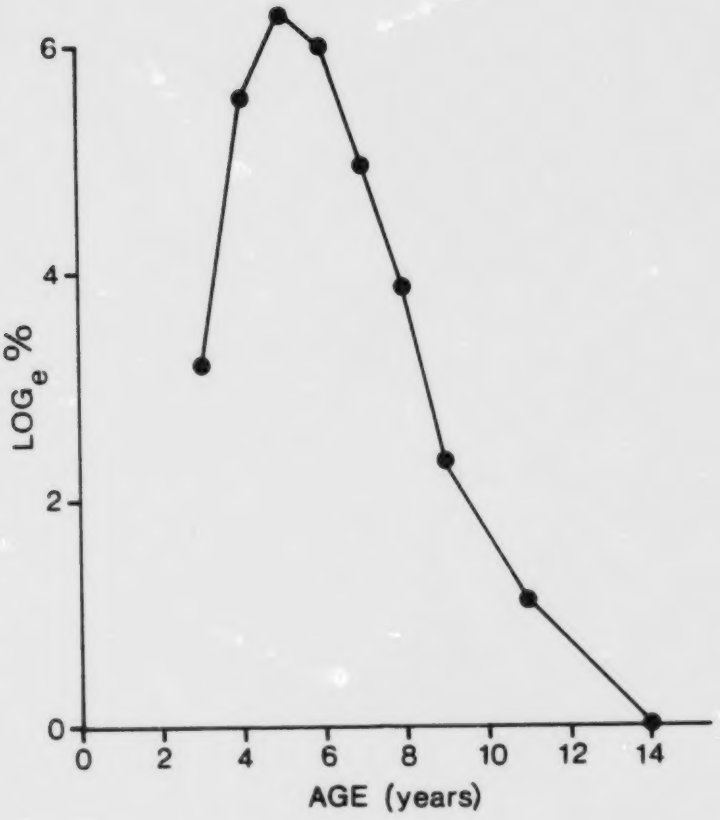

Fig. 7. Catch curve of the northern Lake Winnipeg whitefish stocks, 1979.

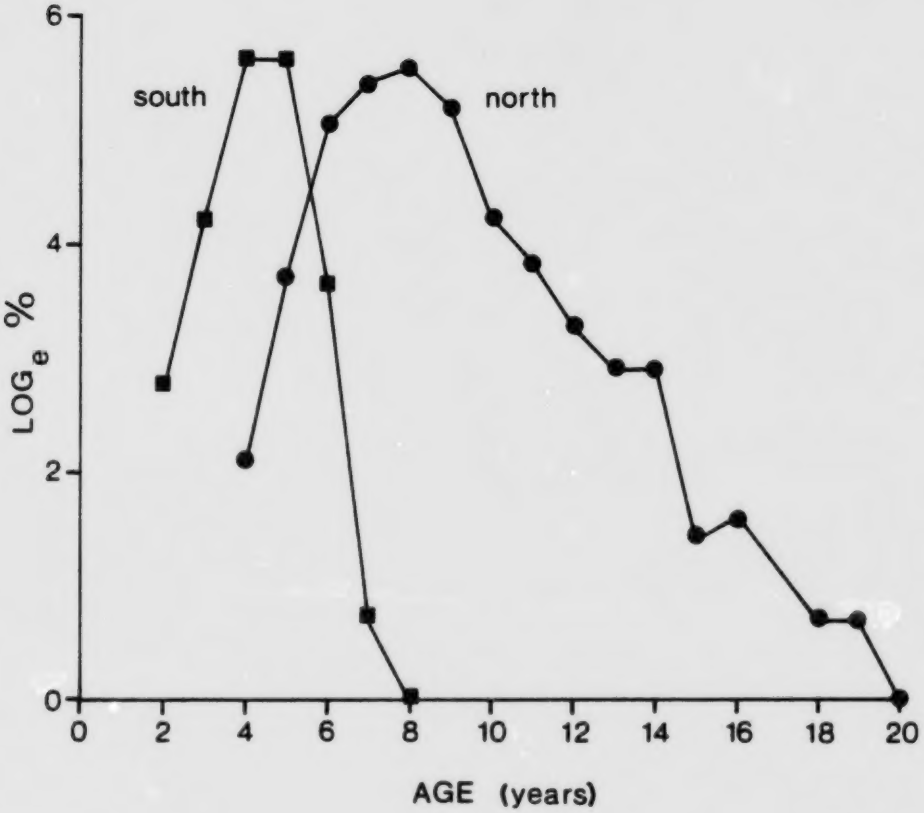

Fig. 8. Catch curves of northern and southern sauger stocks in Lake Winnipeg, 1979.

Table 12. Age-specific mean fork lengths and mean weights of saugers from the three major areas of Lake Winnipeg, 1979.

Age (years)	Area								
	South end			Channel			North end		
	No. fish	Mean length (mm)	Mean weight (gm)	No. fish	Mean length (mm)	Mean weight (gm)	No. fish	Mean length (mm)	Mean weight (gm)
2	16	195.00	97.69	2	191.00	70.00			
3	69	283.22	243.77	21	233.43	123.81			
4	275	292.58	263.76	49	270.98	191.43	8	279.31	273.75
5	268	300.51	286.29	81	284.20	221.85	40	301.28	305.50
6	38	307.55	300.11	28	300.96	270.71	153	318.74	368.76
7	2	297.00	265.00	19	310.26	298.95	223	335.30	430.00
8	1	306.00	350.00	7	339.57	385.71	256	347.77	486.33
9				1	346.00	370.00	179	359.79	541.84
10				1	346.00	380.00	68	378.63	640.15
11							46	386.28	706.09
12							26	408.92	845.00
13							18	375.61	559.44
14							18	382.56	650.00
15							4	441.75	1,127.50
16							5	409.20	800.00
17							0	-	-
18							2	416.00	770.00
19							2	434.00	1,040.00
20							1	408.00	820.00

Table 13. Age-specific mean fork lengths and mean weights of northern Lake Winnipeg whitefish, 1979.

Age (years)	No. fish	Mean length (mm)	Mean weight (gm)
2	1	252.00	260.00
3	24	295.50	361.25
4	249	343.78	601.29
5	545	375.39	781.12
6	400	392.73	898.25
7	138	407.19	1010.00
8	46	428.72	1215.87
9	10	453.90	1485.00
10	1	508.00	2080.00
11	3	516.00	2146.67
14	1	556.00	3420.00

Table 14. Age-specific mean fork lengths and mean weights of walleyes from northern and southern Lake Winnipeg, 1979.

Age (years)	Area					
	South end			North end		
	No. fish	Mean length (mm)	Mean weight (gm)	No. fish	Mean length (mm)	Mean weight (gm)
1	5	186.80	103.60			
2	35	220.20	149.34			
3	143	340.25	422.26	5	295.40	294.00
4	259	353.19	474.46	90	322.34	388.22
5	188	366.82	550.53	124	337.07	460.73
6	59	405.98	747.85	77	366.21	603.90
7	12	421.58	895.42	46	405.87	815.65
8	2	495.00	1,425.00	15	430.20	1014.00
9	3	487.33	1,326.67	3	451.67	1090.00

Table 15. Length-weight relationships of saugers, whitefish and walleyes from the three major areas of Lake Winnipeg.

Species	Area	Length-weight equation	Correlation coefficient	Test F ratio, d.f. and significance at P = 0.05
Sauger	North	$\log_e$ weight = -11.968 + 3.104 $\log_e$ length	0.990	708.1(1, 15) significant
	Channel	$\log_e$ weight = -10.940 + 2.893 $\log_e$ length	0.998	2040.86(1, 8) significant
	South	$\log_e$ weight = - 8.844 + 2.544 $\log_e$ length	0.988	197.14(1, 6) significant
Whitefish	North	$\log_e$ weight = -12.215 + 3.191 $\log_e$ length	0.995	862.64(1, 9) significant
Walleye	North	$\log_e$ weight = -12.254 + 3.156 $\log_e$ length	0.998	1570.02(1, 5) significant
	South	$\log_e$ weight = - 9.490 + 2.685 $\log_e$ length	0.996	888.99(1, 7) significant

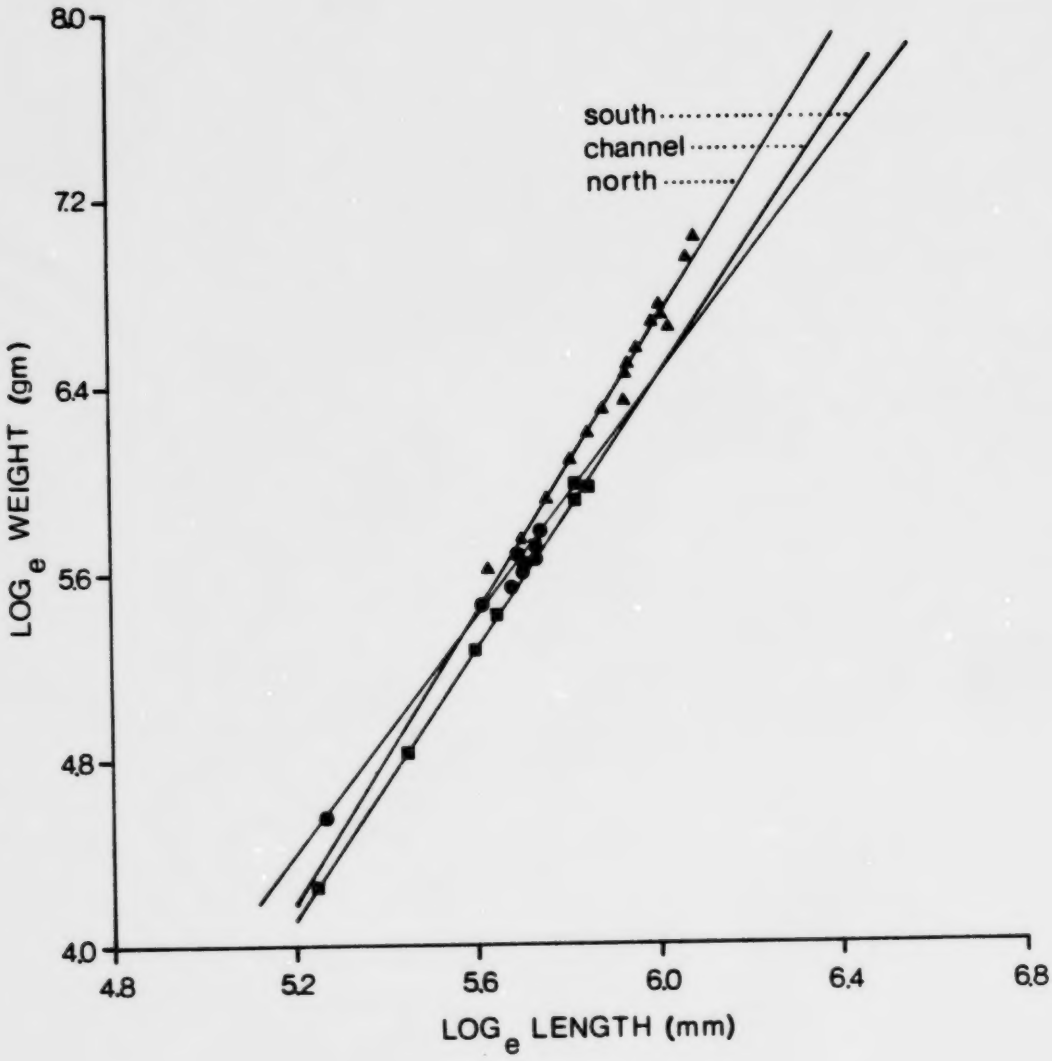

Fig. 9. Length-weight relationships of northern, channel and southern saugers from Lake Winnipeg, 1979.

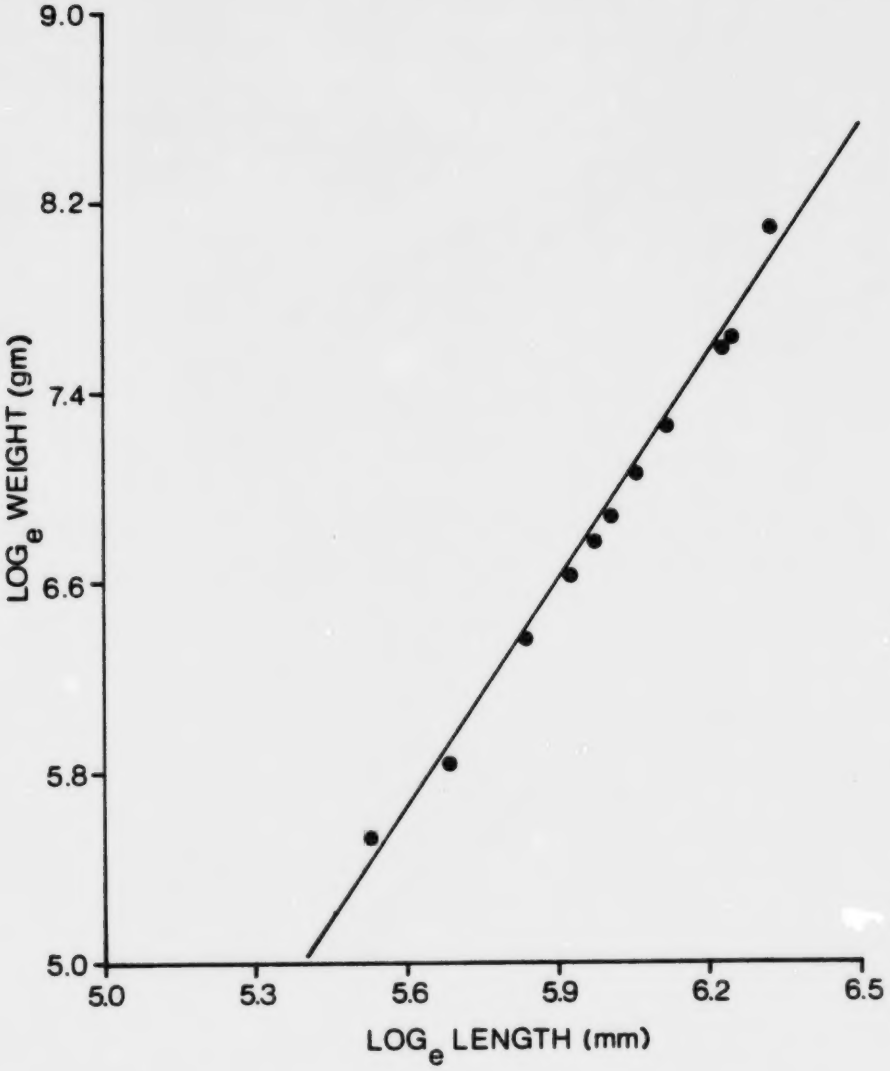

Fig. 10. Length-weight relationship of Lake Winnipeg whitefish, 1979.

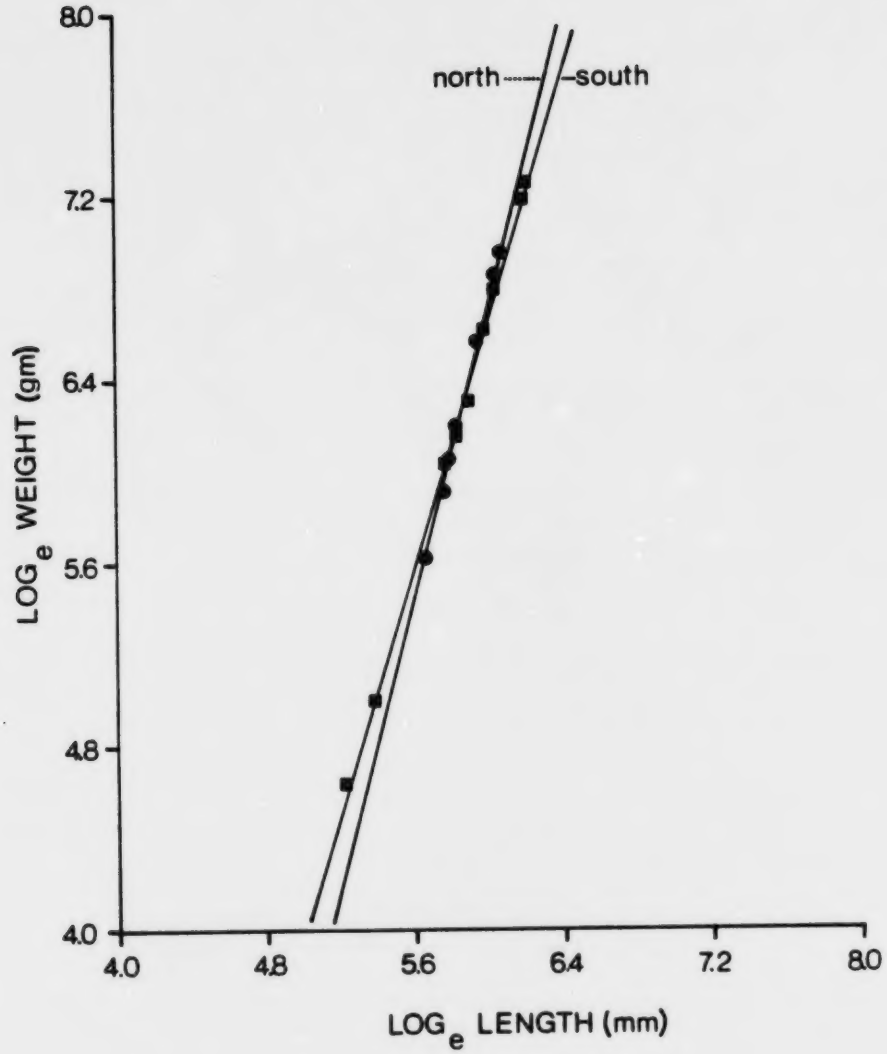

Fig. 11. Length-weight relationships of northern and southern walleyes from Lake Winnipeg, 1979.

among the curves ($F = 4.737$, 2 and 26 d.f., $P = 0.05$). Northern sauger growth is positively allometric while channel and southern sauger growth is negatively allometric (Table 15). Growth of northern whitefish is positively allometric (Table 15). Covariance analysis of logtransformed walleye length-weight curves from northern and southern Lake Winnipeg showed significant differences between the curves ($F = 6.12$, 1 and 12 d.f., $P = 0.05$). Northern walleye growth is positively allometric while southern walleye growth is negatively allometric (Table 15).

Walford plots for saugers from the three major areas of Lake Winnipeg (Fig. 12) showed significant relationships of L_{t+1} and L_t for southern, channel and northern saugers (Table 16). The L_∞ estimate for northern saugers was the highest of all three areas.

A Walford plot for whitefish from northern Lake Winnipeg (Fig. 13) estimated $L_\infty = 938$ mm (Table 16).

A Walford plot for southern walleyes estimated $L_\infty = 511$ mm (Fig. 14). Since the slope of the northern walleye Walford plot was 0.999, the corresponding estimate of L_∞ was unrealistically high (Table 16).

To determine growth rates, untransformed growth curves of saugers (Fig. 15), whitefish (Fig. 16) and walleyes (Fig. 17) were transformed into straight lines using various transformations (Table 17). Correlation coefficients of regressions of $\log_e (L_\infty - 1_t)$ on t (Fig. 18 - 20) were considered to represent the von Bertalanffy growth curve since these regressions provided estimates of parameters comprising the von Bertalanffy equation. The von Bertalanffy transformation

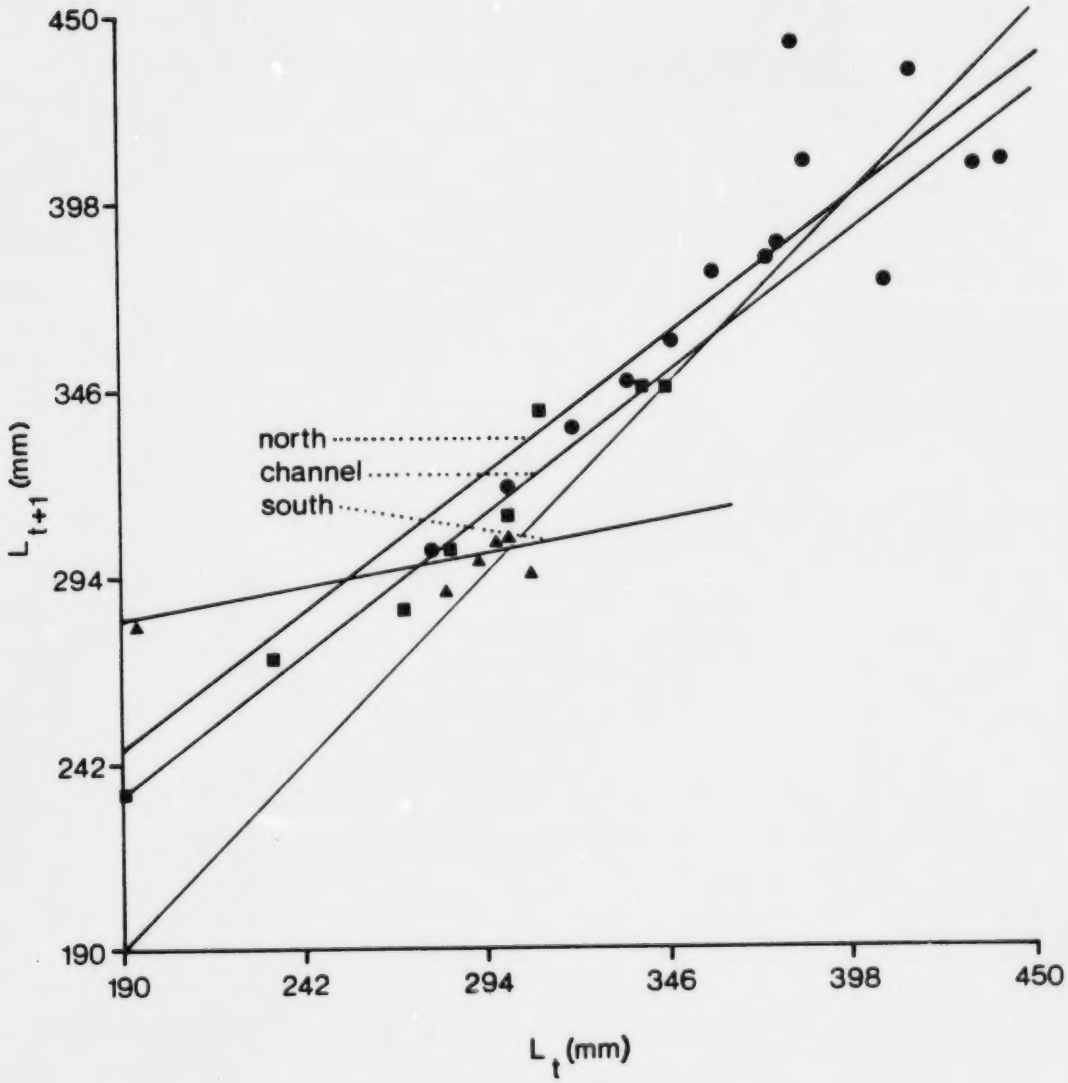

Fig. 12. Walford plots of northern, channel and southern saugers from Lake Winnipeg, 1979.

Table 16. Linear equations of Walford plots fitted by least squares regression.

Species	Area	Linear equation	L_∞ (mm)	Correlation coefficient	Test F ratio, d.f. and significance at P = 0.05
Sauger	North	$L_{t+1} = 105.526 + 0.738L_t$	402	0.861	34.48(1, 13) significant
	Channel	$L_{t+1} = 90.417 + 0.750L_t$	361	0.980	145.45(1, 7) significant
	South	$L_{t+1} = 248.188 + 0.178L_t$	301	0.826	8.57(1, 5) significant
Whitefish	North	$L_{t+1} = 52.731 + 0.944L_t$	938	0.984	236.58(1, 8) significant
Walleye	North	$L_{t+1} = 26.534 + 0.999L_t$	-	0.987	151.32(1, 4) significant
	South*	$L_{t+1} = 59.926 + 0.882L_t$	511	0.991	228.55(1, 4) significant

* L_2 and L_7 (Table 14) were deleted from the analysis.

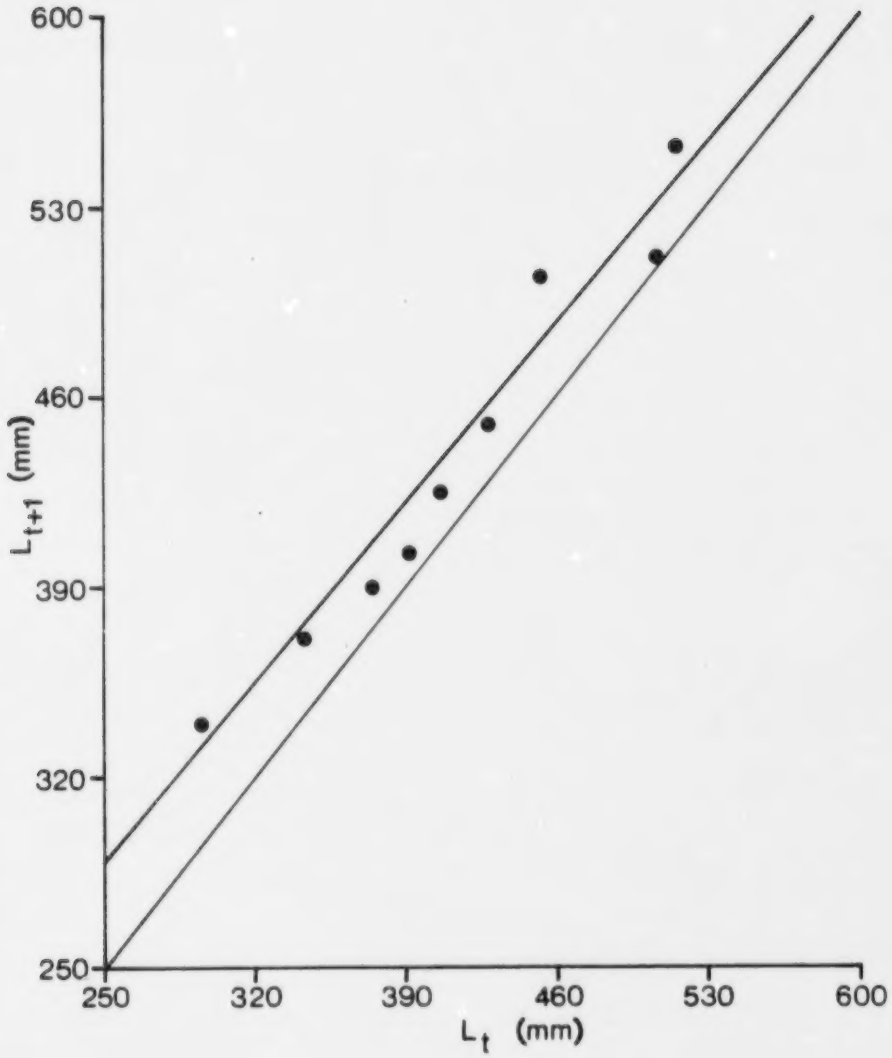

Fig. 13. Walford plot of whitefish mean lengths.

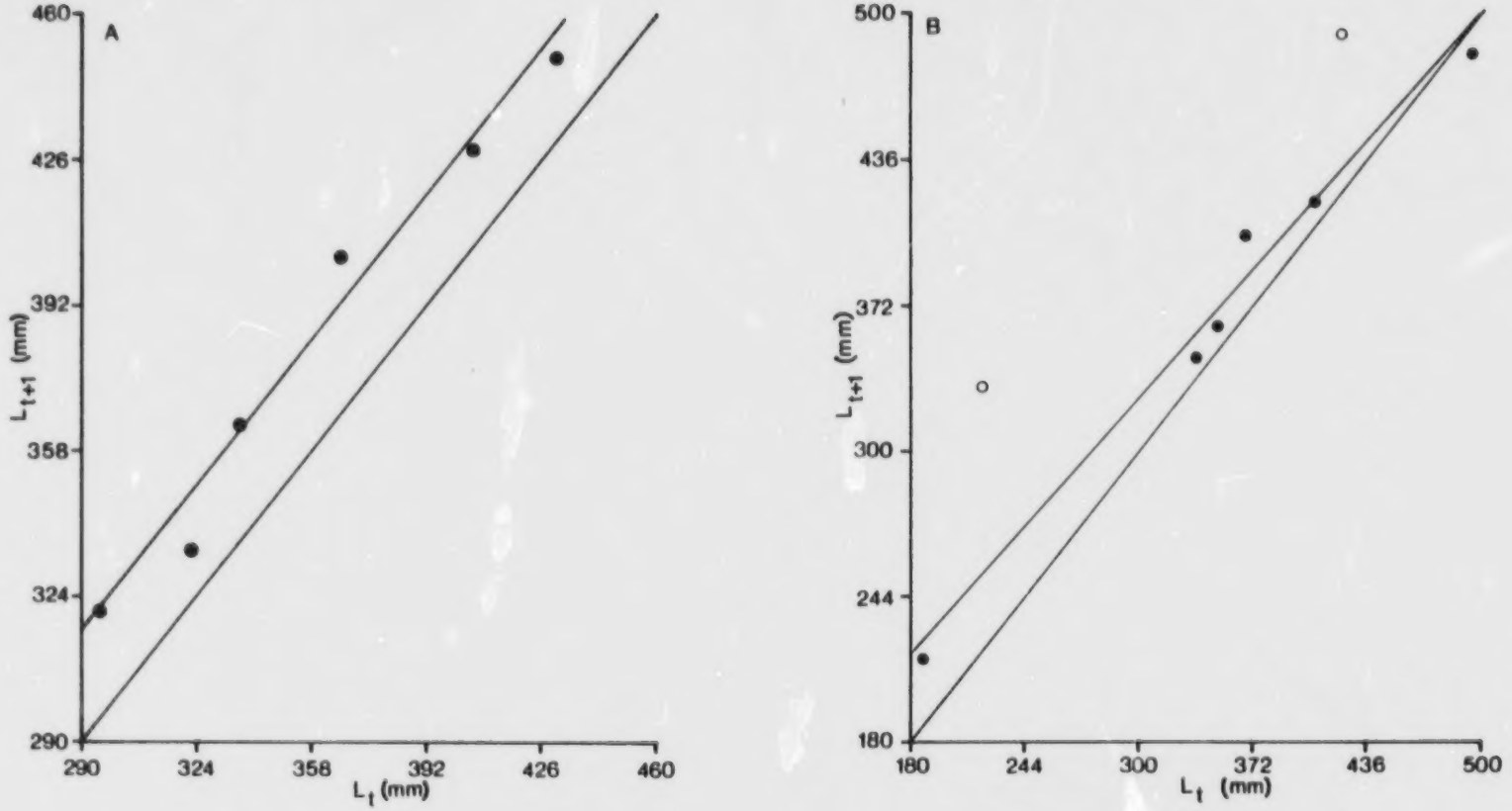

Fig. 14. Walford plots of northern (A) and southern (B) walleye mean lengths. Lengths denoted by open circles were omitted from the analysis.

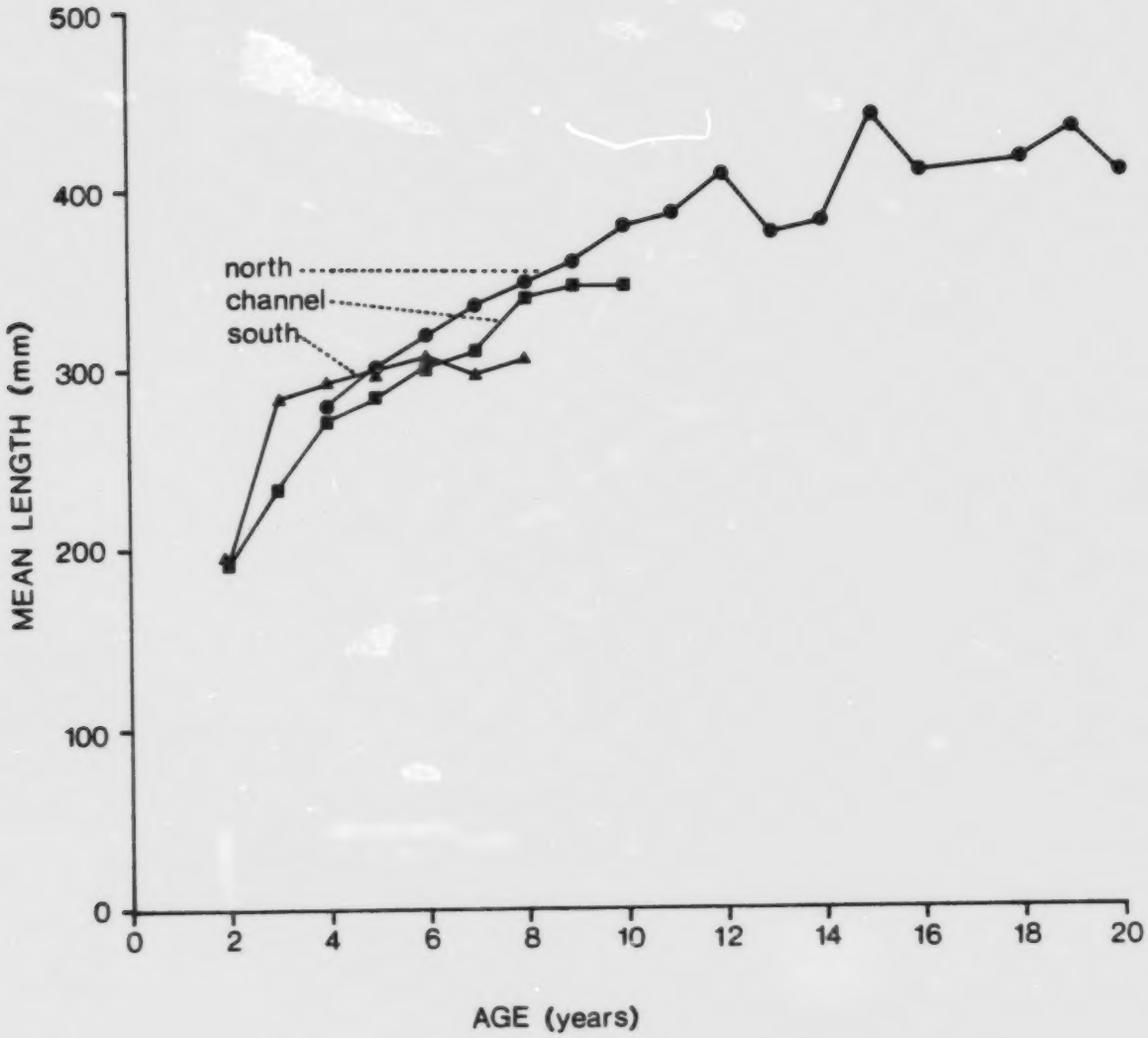

Fig. 15. Temporal changes in mean lengths of northern channel and southern saugers from Lake Winnipeg, 1979. The last four ages of northern saugers were determined from otoliths.

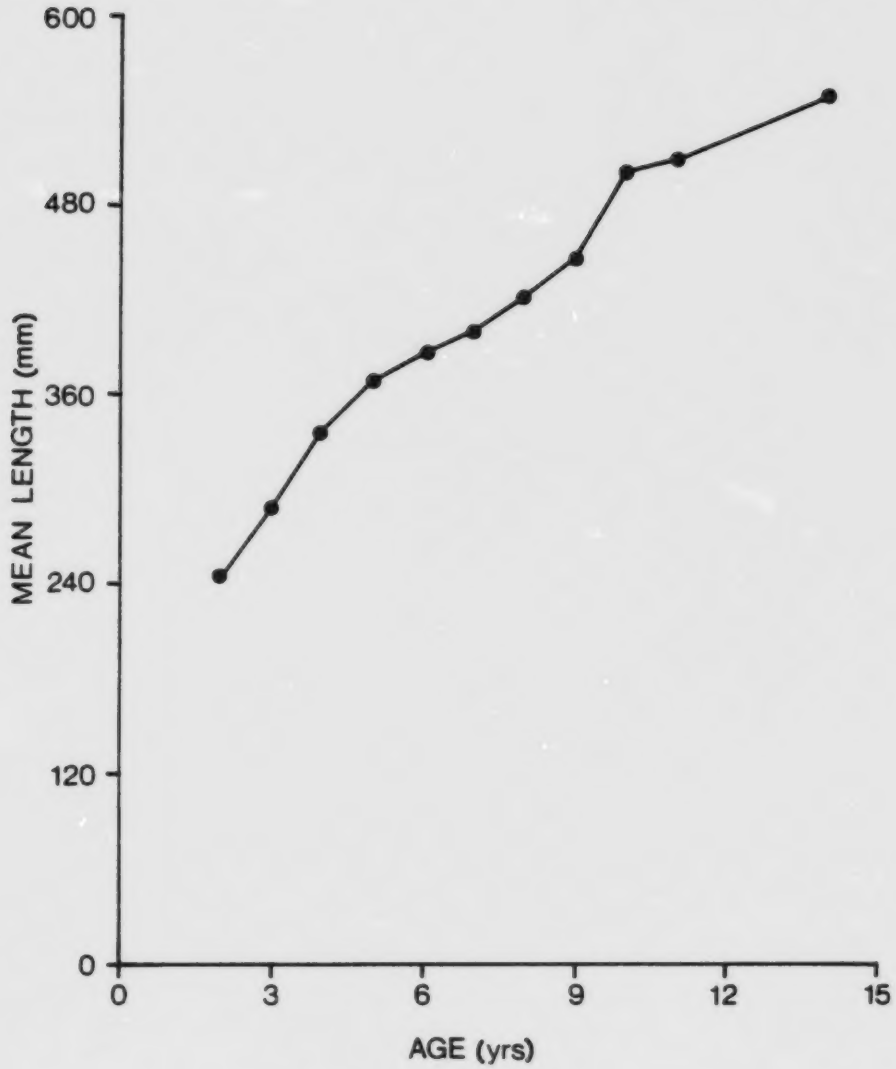

Fig. 16. Temporal changes in mean lengths of whitefish from Lake Winnipeg, 1979.

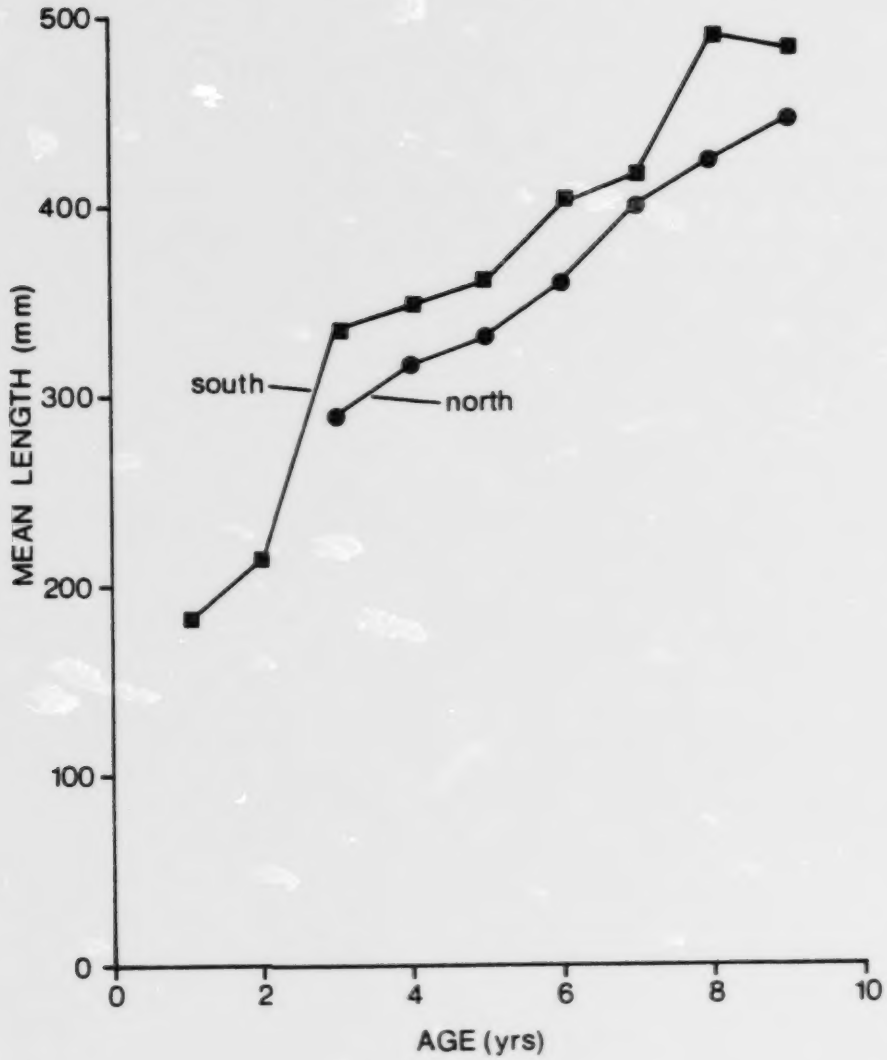

Fig. 17. Temporal changes in mean lengths of northern and southern walleyes from Lake Winnipeg, 1979.

Table 17. Correlation coefficients of untransformed and transformed growth curves.

Species	Area	Transformation			
		Untransformed	Log_e(age)	Full log_e	$Log_e(L_\infty - l_t)$ vs t
Sauger	North	0.930	0.951	0.960	-0.977
	Channel	0.980	0.985	0.988	-0.979
	South	0.832	0.904	0.889[1],0.967[2]	-0.982
Whitefish	North	0.982	0.984	0.994	-0.990
Walleye	North	0.995	0.977	0.986	-
	South	0.964	0.970	0.978	-0.982

[1] lengths at ages 7,8 deleted.

[2] lengths at ages 2,7,8 deleted.

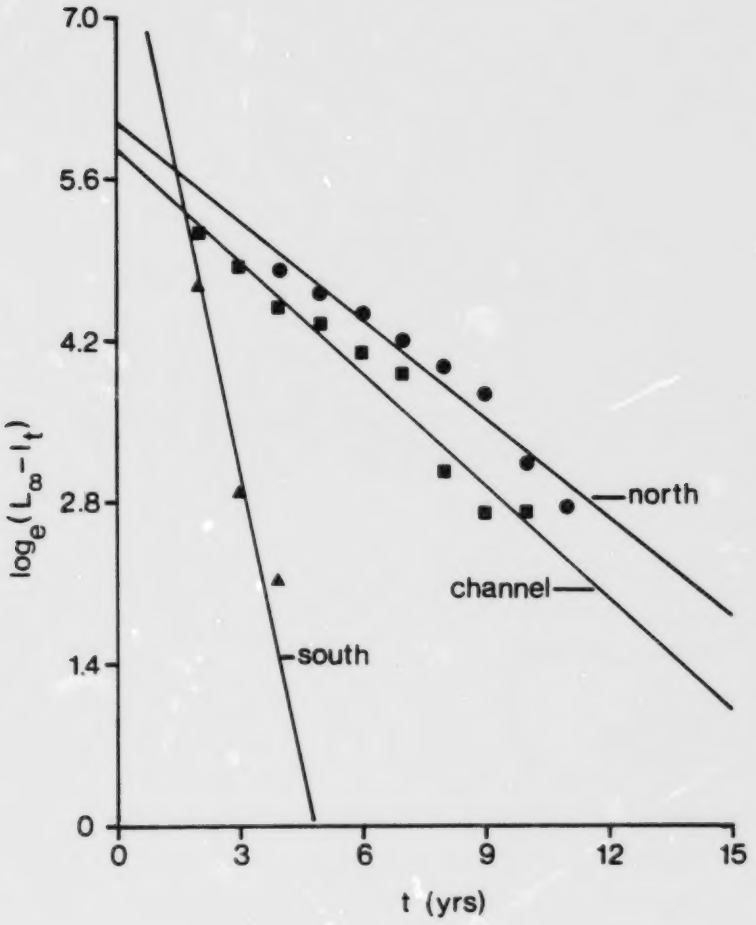

Fig. 18. Linear regressions of $L_\infty - l_t$ versus t for northern, channel and southern Lake Winnipeg saugers, 1979.

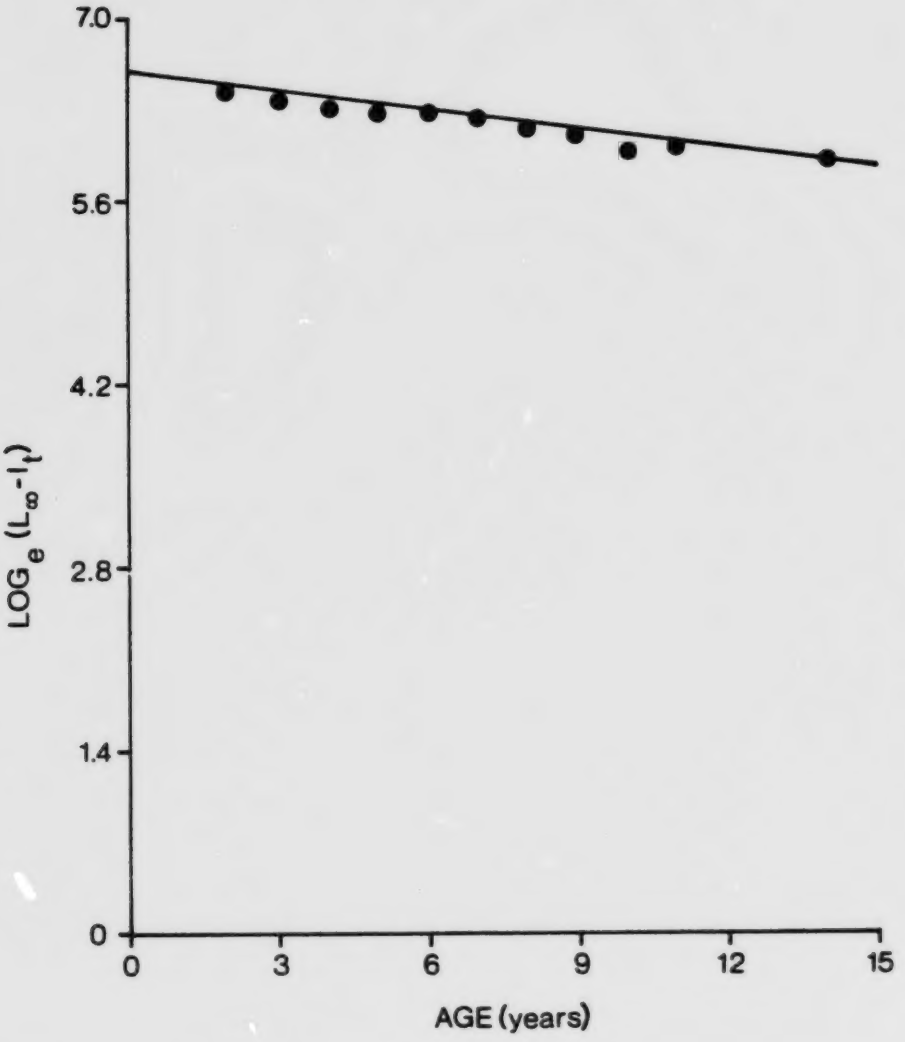

Fig. 19. Linear regression of $L_\infty - l_t$ versus t for Lake Winnipeg whitefish, 1979.

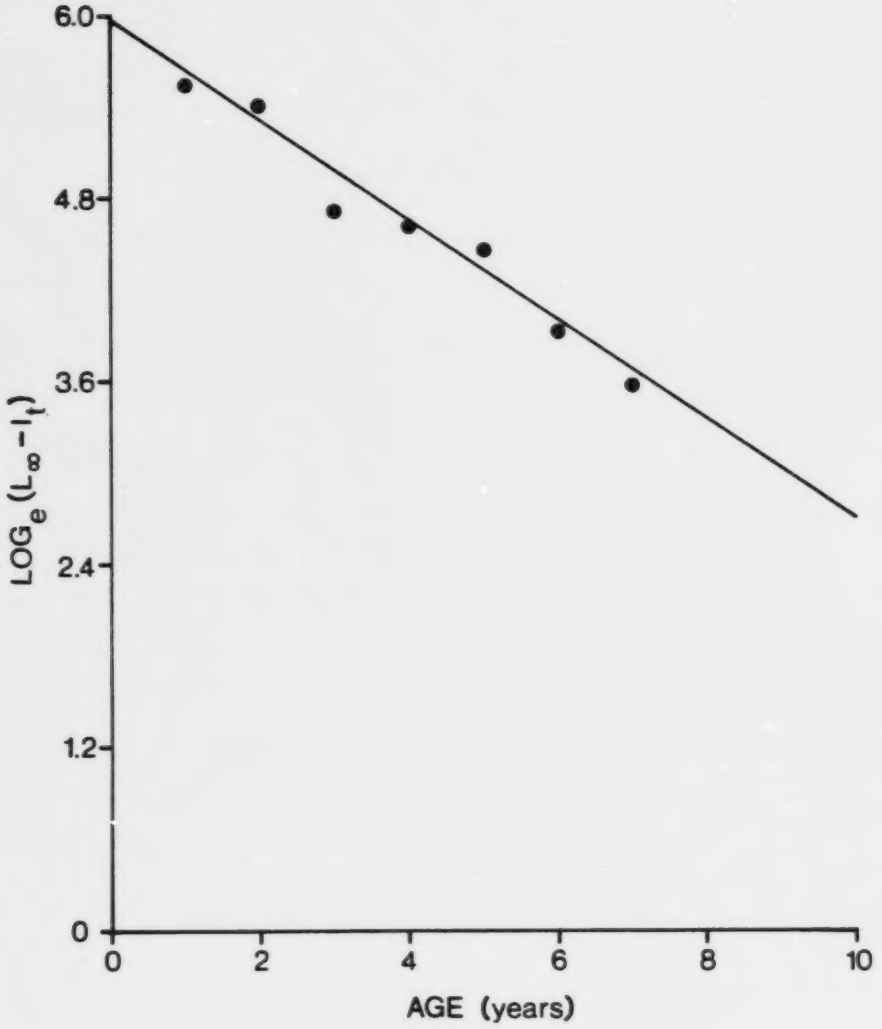

Fig. 20. Linear regression of $L_\infty - l_t$ versus t for southern Lake Winnipeg walleyes, 1979.

produced the highest correlation coefficients for Channel saugers and northern whitefish (Table 17). Exponential and von Bertalanffy growth curves of saugers both indicate that growth rates increase and asymptotic sizes decrease from the north to the south of Lake Winnipeg (Table 18, Fig. 21). Since L_{∞} could not be estimated for northern walleyes, it was impossible to directly relate the southern walleye von Bertalanffy curve (Fig. 22) to its northern counterpart. However, the exponential growth curves of walleyes indicate that walleyes grow faster in the south end (Table 18). Whitefish growth is relatively slow and asymptotic size is not attained for at least 20 years (Table 18, Fig. 23).

Differences between scale ages and otolith ages

Otolith ages were significantly different from scale ages for all ages except those of two year old saugers from the south basin (Fig. 24). In general, differences between otolith ages and scale ages were greatest for northern saugers and were the least for southern saugers (Appendix B).

Net selectivity

With respect to saugers, net selectivity of the experimental gang was greatest in the north basin, relatively less in the channel and virtually non-existent in the south basin (Figs. 25 - 27). Notice that the 4.25 inch curve of channel saugers was bimodal and that younger fish were present in larger meshes (Fig. 26).

Net selectivity with respect to walleye ages was more pronounced in the north than in the south (Figs. 28, 29). The 4

Table 18. Fitted growth curves of Lake Winnipeg stocks, 1979.

Species	Area	Growth curves	
		Log_e length = a + b · log age	$L_t = L_\infty (1 - e^{-k(t - t_o)})$
Sauger	North	$\log_e$ length = 5.250 + 0.287 $\log_e$ age	$L_t = 402\ (1 - e^{-0.285(t - 0.358)})$
	Channel	$\log_e$ length = 5.041 + 0.368 $\log_e$ age	$L_t = 361\ (1 - e^{-0.285(t - 0.067)})$
	South	$\log_e$ length = 5.097 + 0.387 $\log_e$ age[1]	$L_t = 301\ (1 - e^{-1.688(t + 1.445)})$
		$\log_e$ length = 5.000 + 0.436 $\log_e$ age[2]	
Whitefish	North	$\log_e$ length = 5.250 + 0.407 $\log_e$ age	$L_t = 938\ (1 - e^{-0.049(t + 4.902)})$
Walleye	North	$\log_e$ length = 5.224 + 0.397 $\log_e$ age	
	South	$\log_e$ length = 5.212 + 0.445 $\log_e$ age	$L_t = 460\ (1 - e^{-0.326(t - 0.475)})$

[1] lengths at ages 7 & 8 deleted, r = 0.889

[2] lengths at ages 2, 7 & 8 deleted, r = 0.967

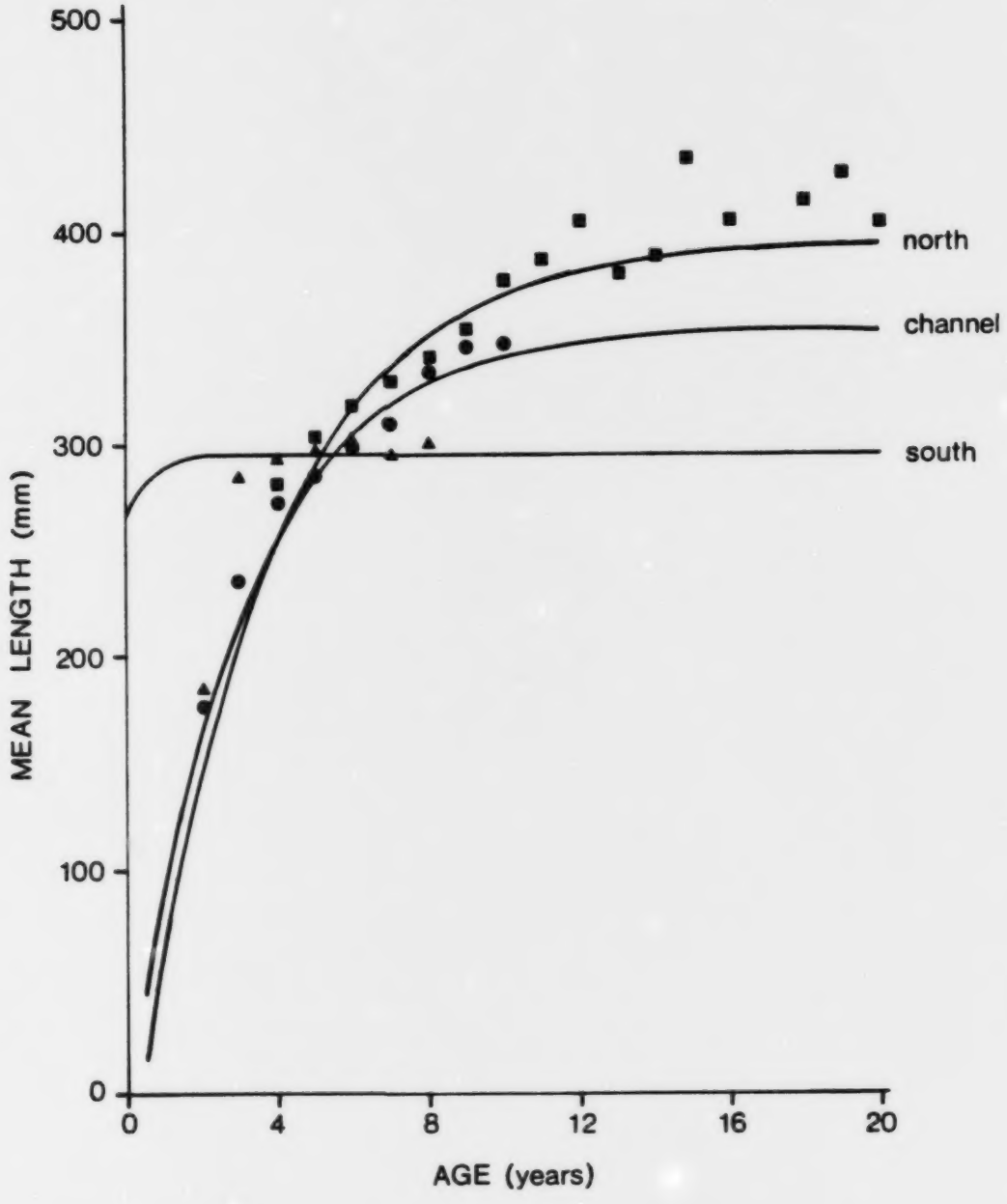

Fig. 21. Von Bertalanffy growth curves of northern, channel and southern saugers from Lake Winnipeg, 1979.

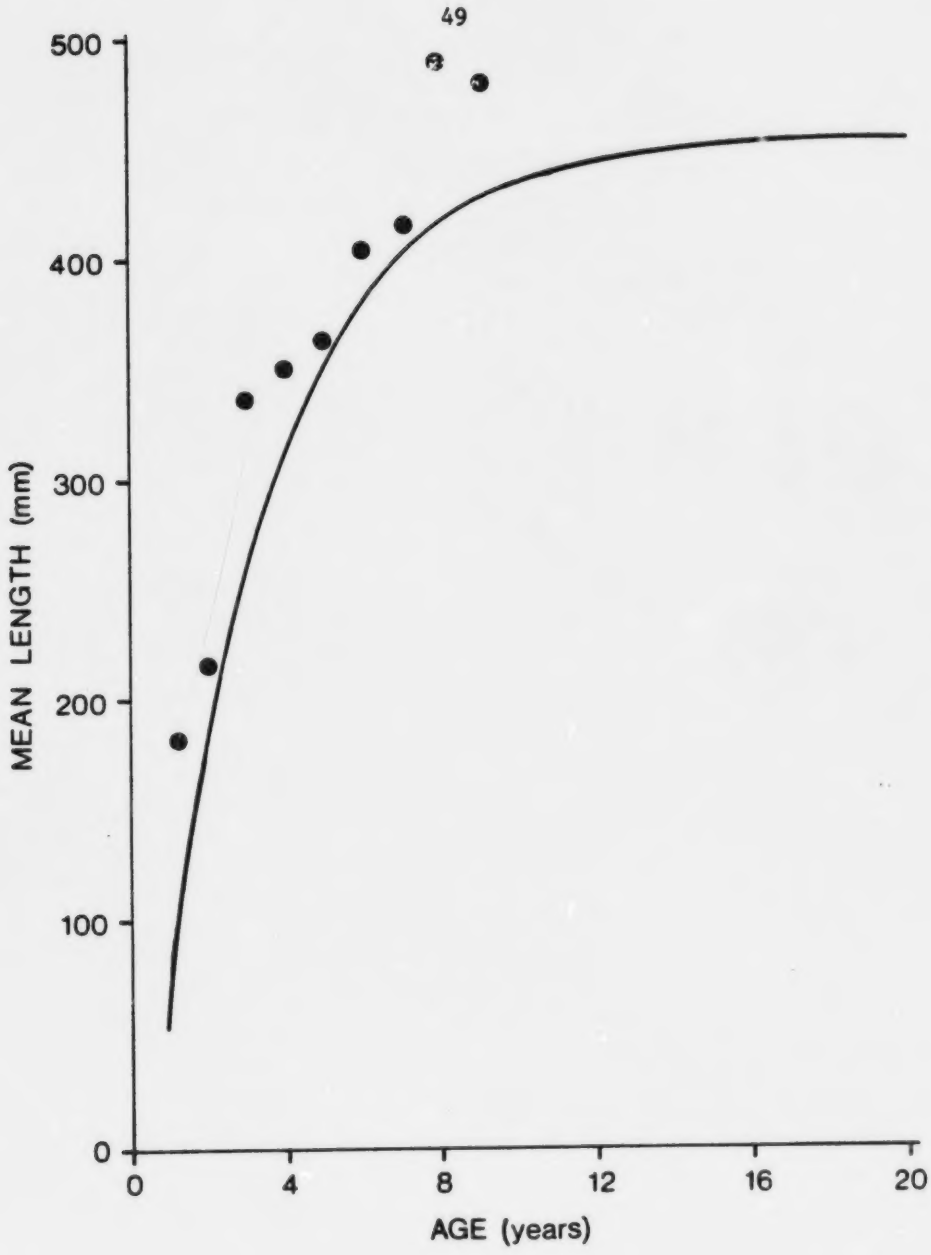

Fig. 22. Von Bertalanffy growth curve of southern Lake Winnipeg walleyes, 1979.

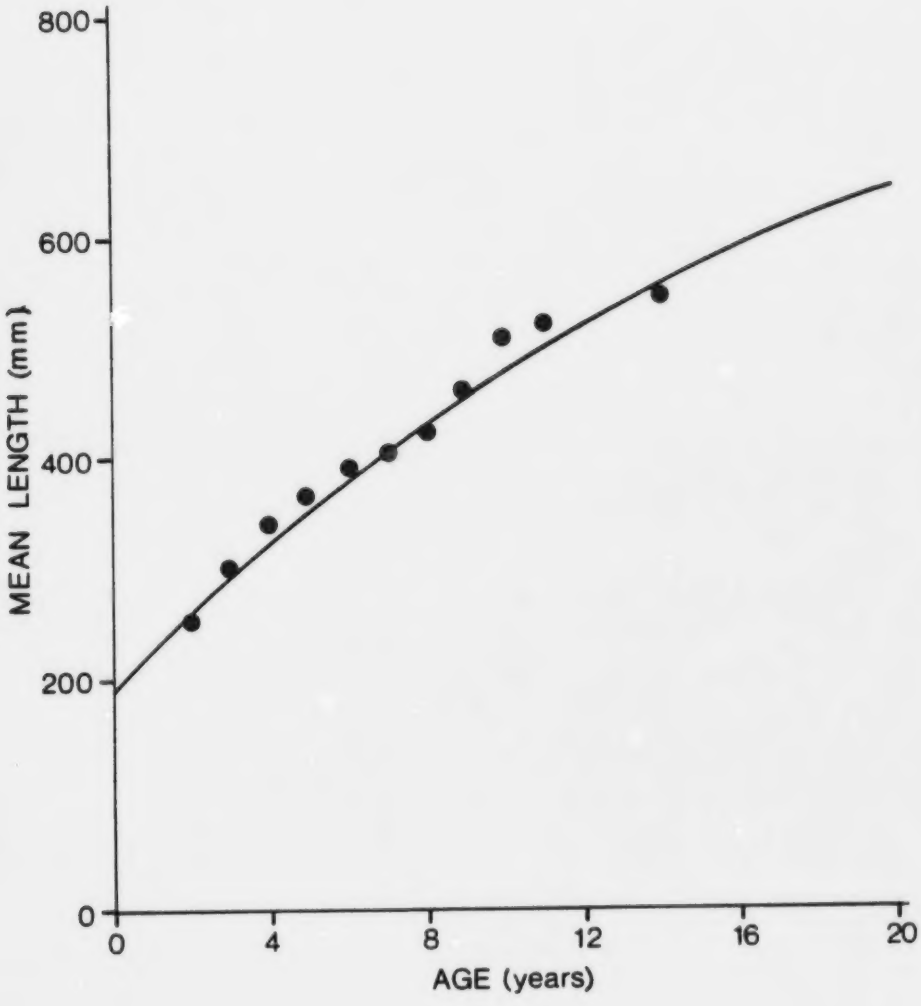

Fig. 23. Von Bertalanffy growth curve of whitefish from Lake Winnipeg, 1979.

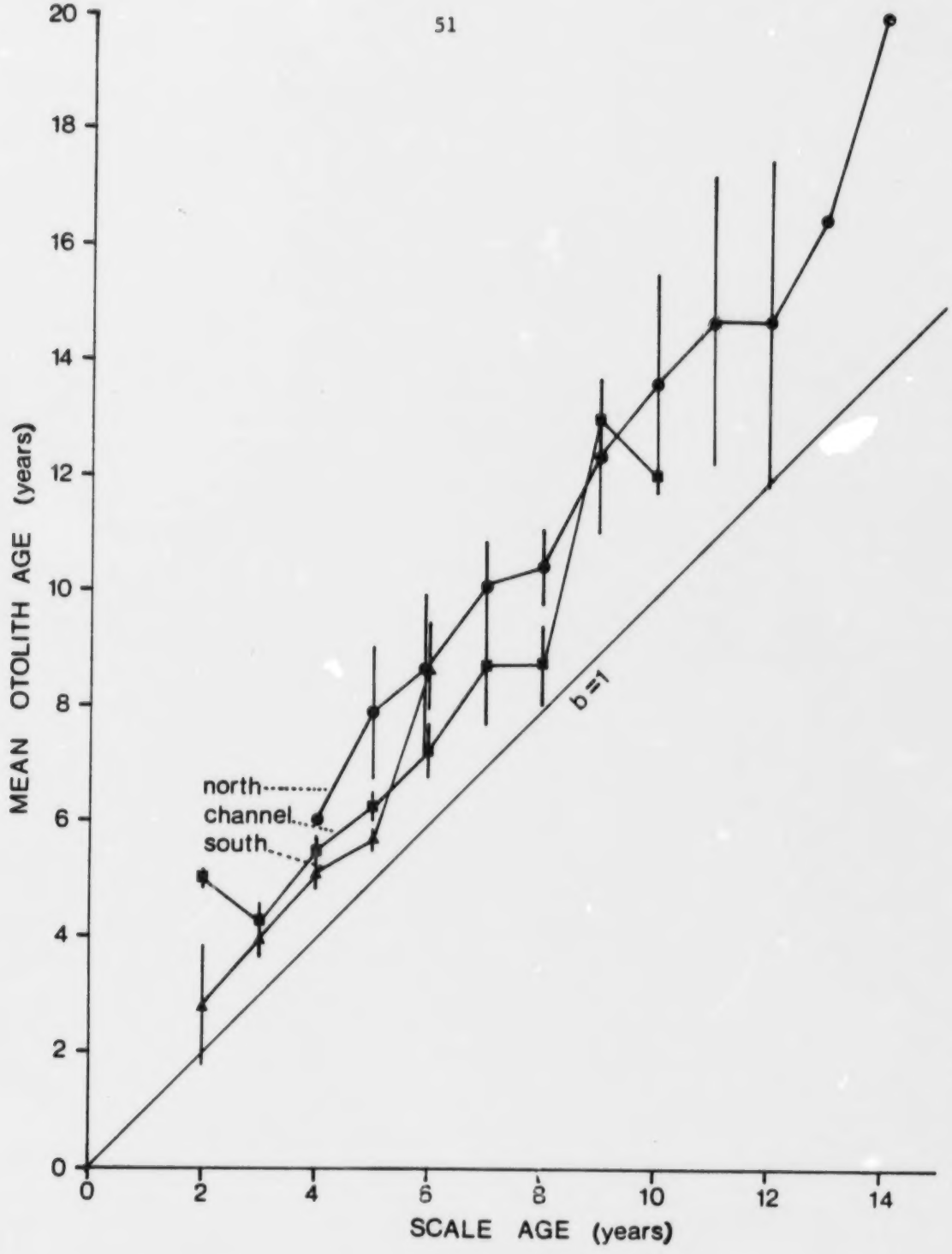

Fig. 24.. Differences between scale ages and mean otolith ages of saugers from the northern, channel and southern areas of Lake Winnipeg. Vertical bars are 95% confidence intervals about the age-specific mean otolith ages. The slope of the agreement line is 1.

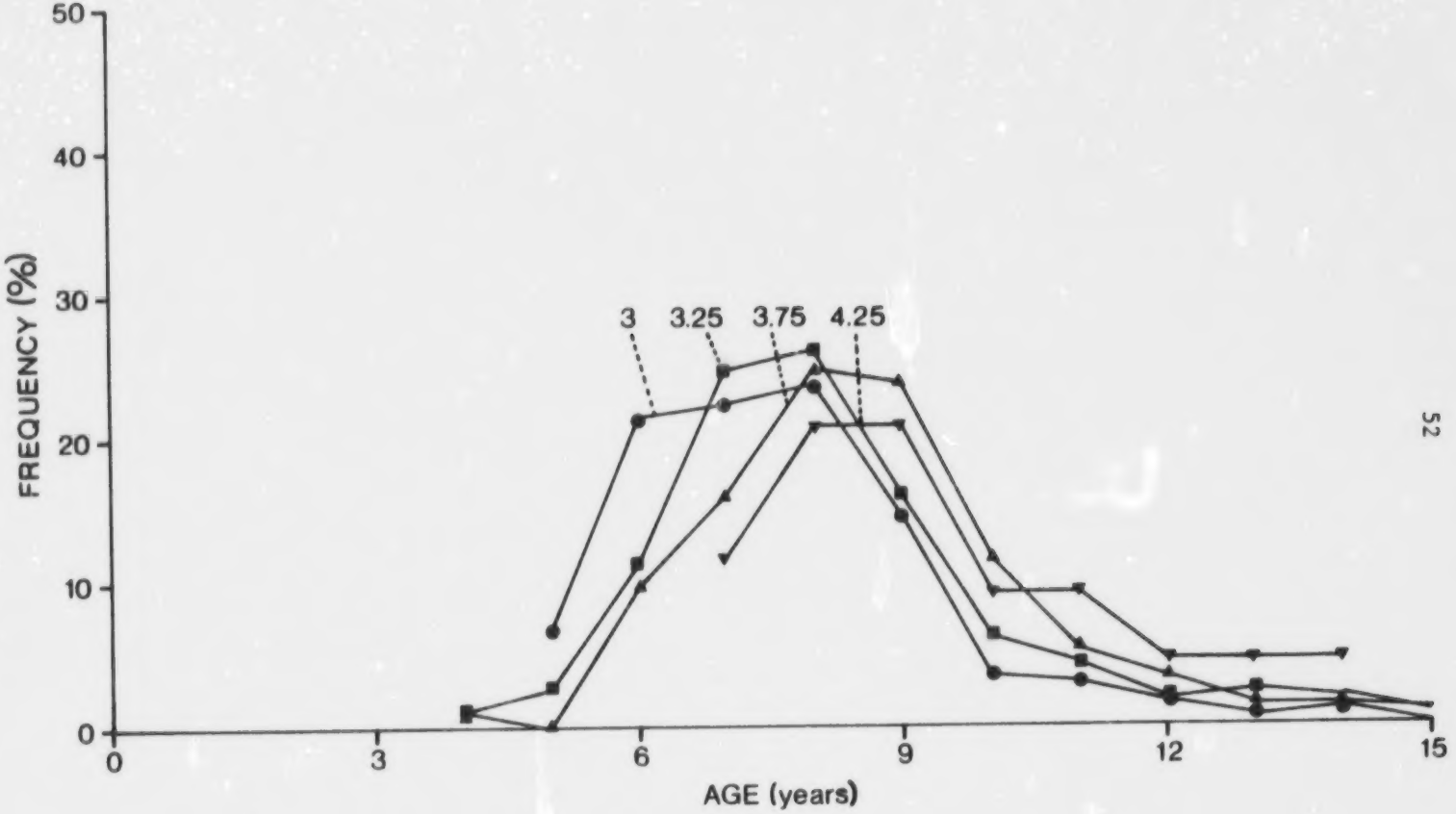

Fig. 25. Net selectivity with respect to ages of northern saugers.

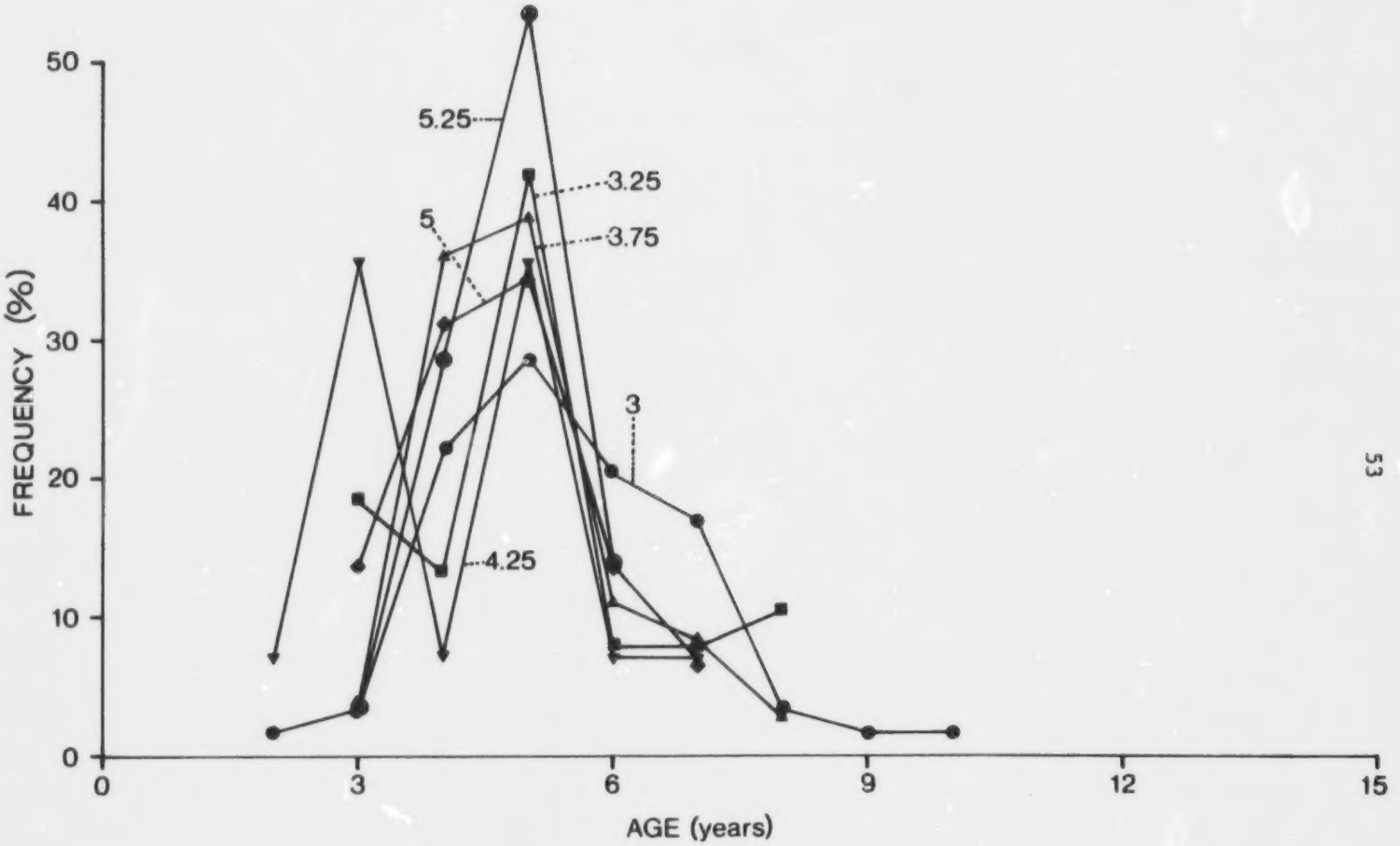

Fig. 26. Net selectivity with respect to ages of channel saugers.

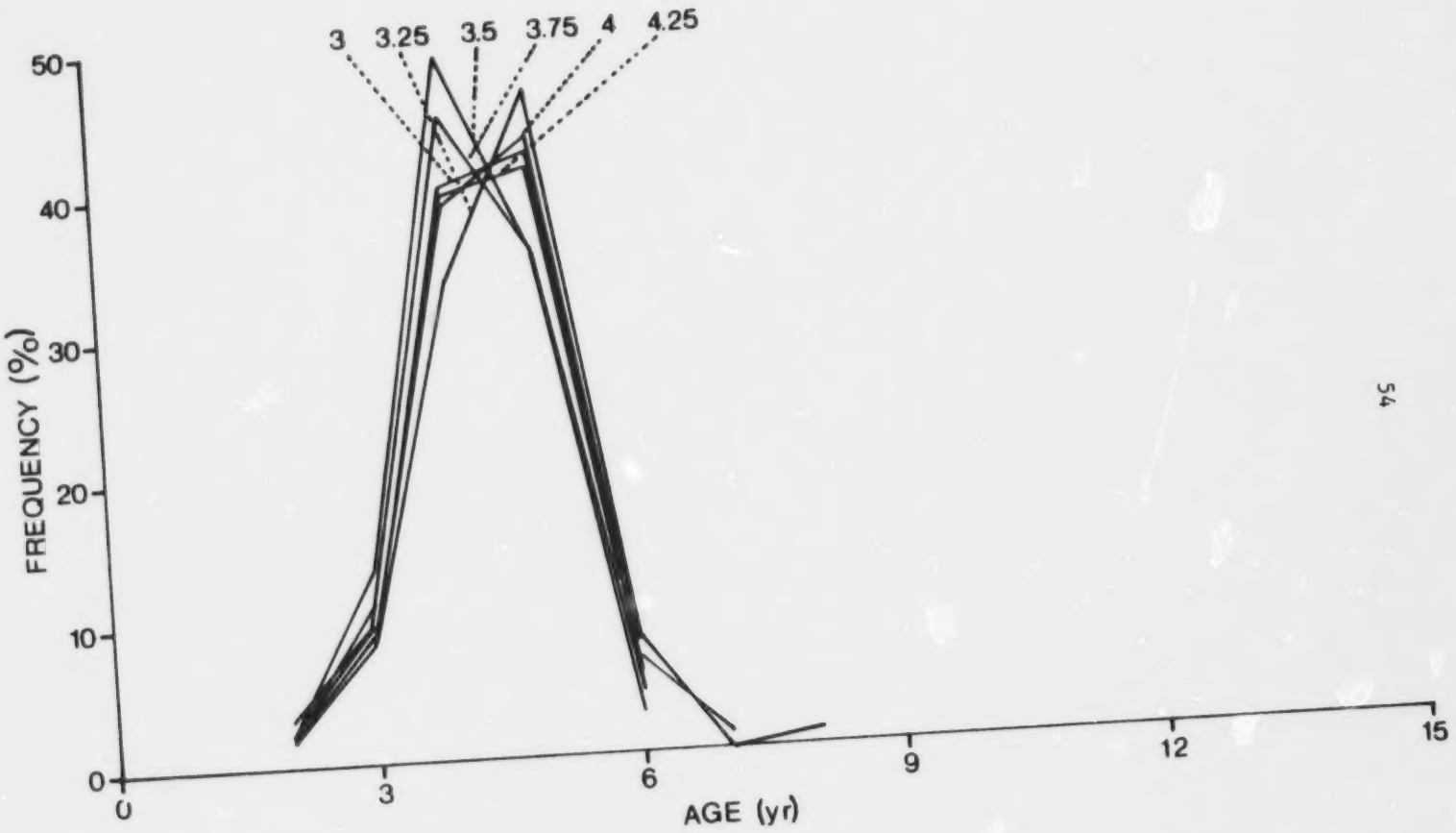

Fig. 27. Net selectivity with respect to ages of southern saugers.

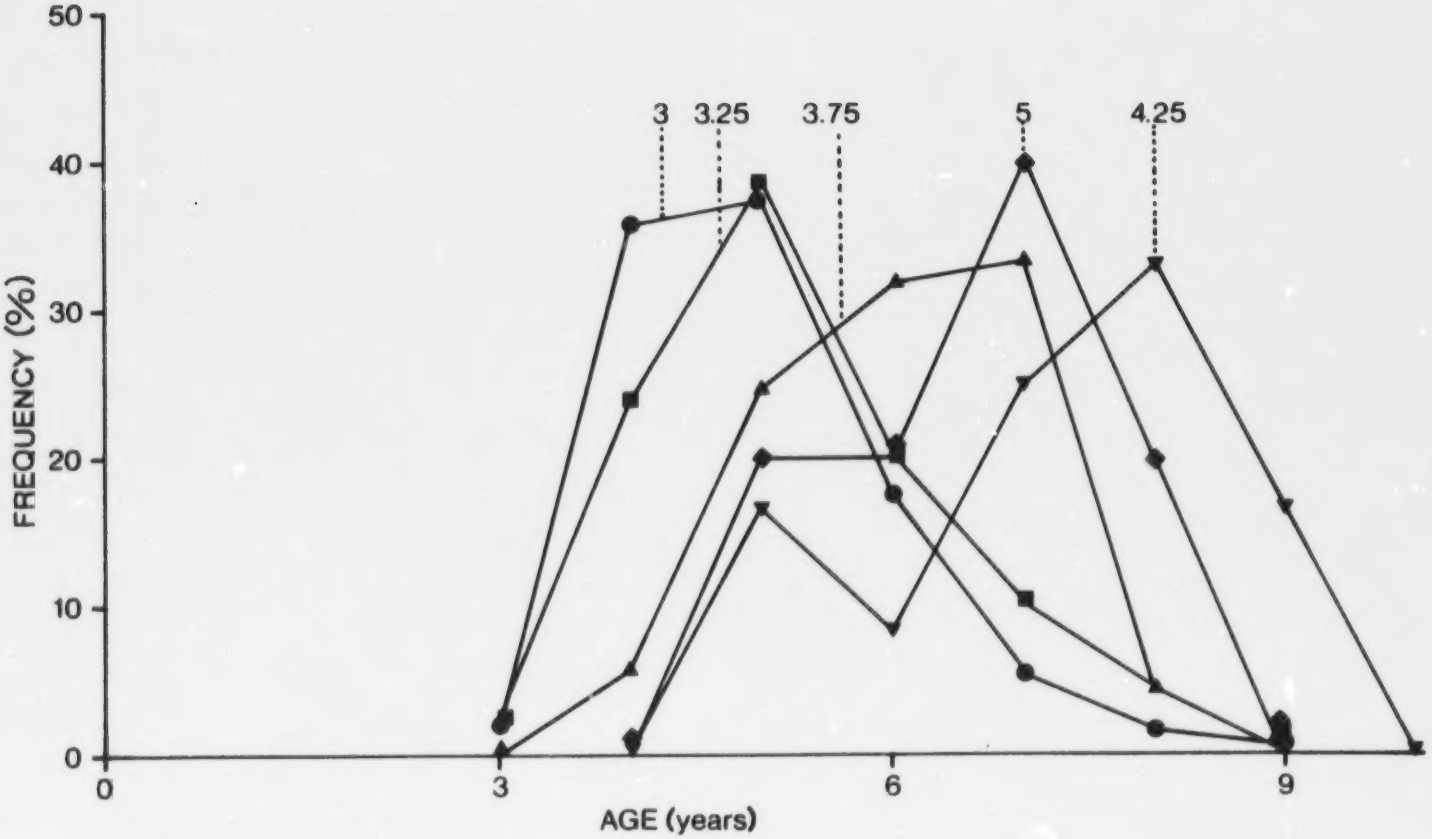

Fig. 28. Net selectivity with respect to ages of northern walleyes.

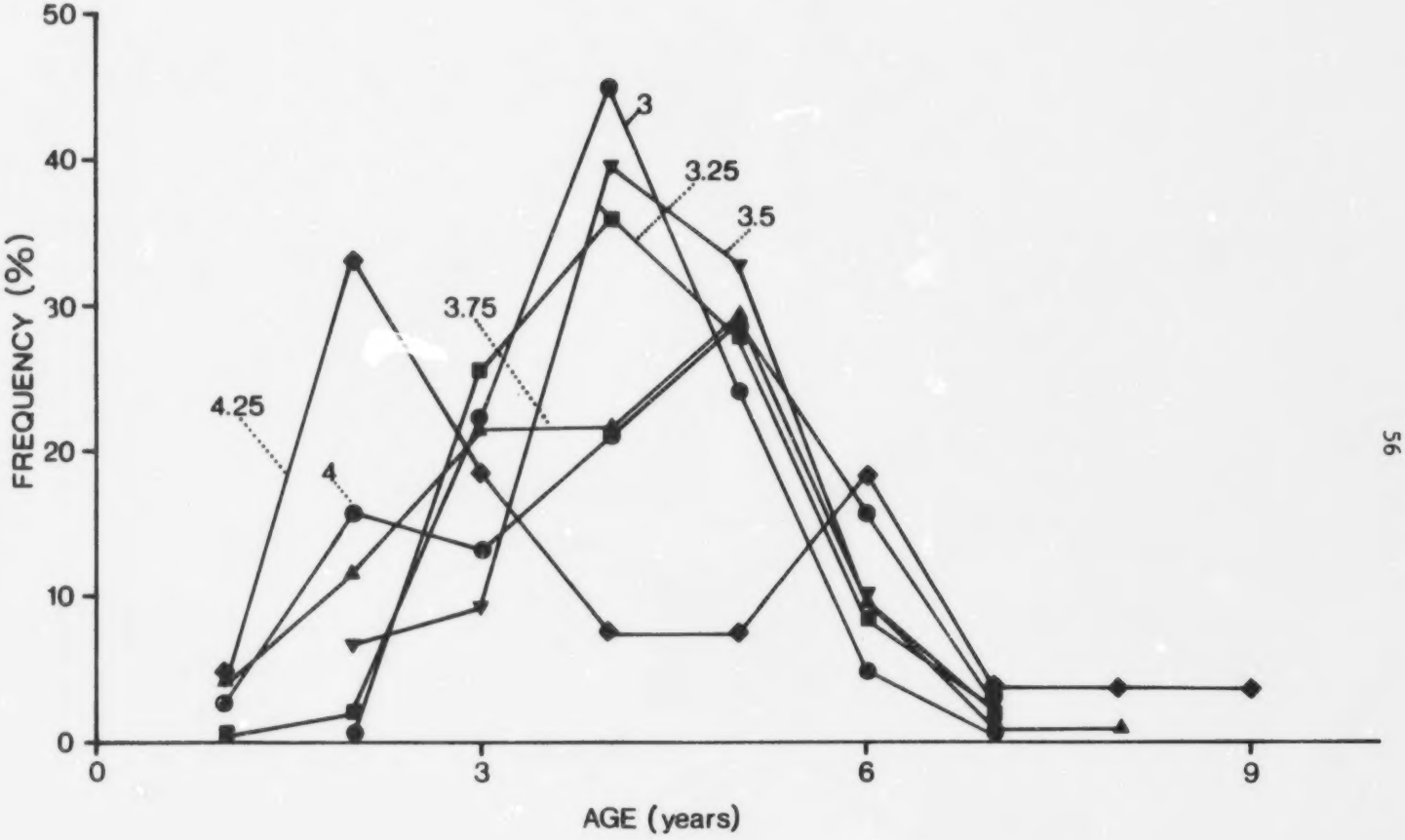

Fig. 29. Net selectivity with respect to ages of southern walleyes.

and 4.25 inch meshes in the south basin tended to catch relatively young and relatively old walleyes while the ages caught by smaller meshes were intermediate (Fig. 29).

Net selectivity with respect to whitefish ages was the most pronounced of all the species considered in this analysis. The peaks of mesh-specific whitefish age distributions were widely separated except for the age distributions of the 3.75 and 4.25 inch meshes (Fig. 30).

Mesh size effects

In each of the three major areas the 3 inch mesh caught the highest numbers of saugers. The 3 and 3.25 inch meshes caught two to three times as many saugers in the north basin as they did in the south basin. Mean numbers of saugers per mesh declined more rapidly from the 3 inch to 4.25 inch meshes in the north basin than in the south basin (Fig. 31) but the mean lengths (Fig. 32) and mean weights (Fig. 33) of northern saugers increased with mesh size whereas they decreased with increasing mesh size in the south end. The mean numbers, lengths and weights of channel saugers per mesh were the lowest of all three areas for 3 to 4.25 inch meshes (Figs. 31 - 33). The mean sauger biomass per mesh was much higher in the north than in the channel and south for 3 to 4.25 inches meshes (Fig. 34).

Frequencies of immature saugers continuously declined with increasing mesh size in the north basin. 4.25 + inch meshes caught no immature saugers in the north end. Conversely, frequencies of immature saugers were not related to mesh size in

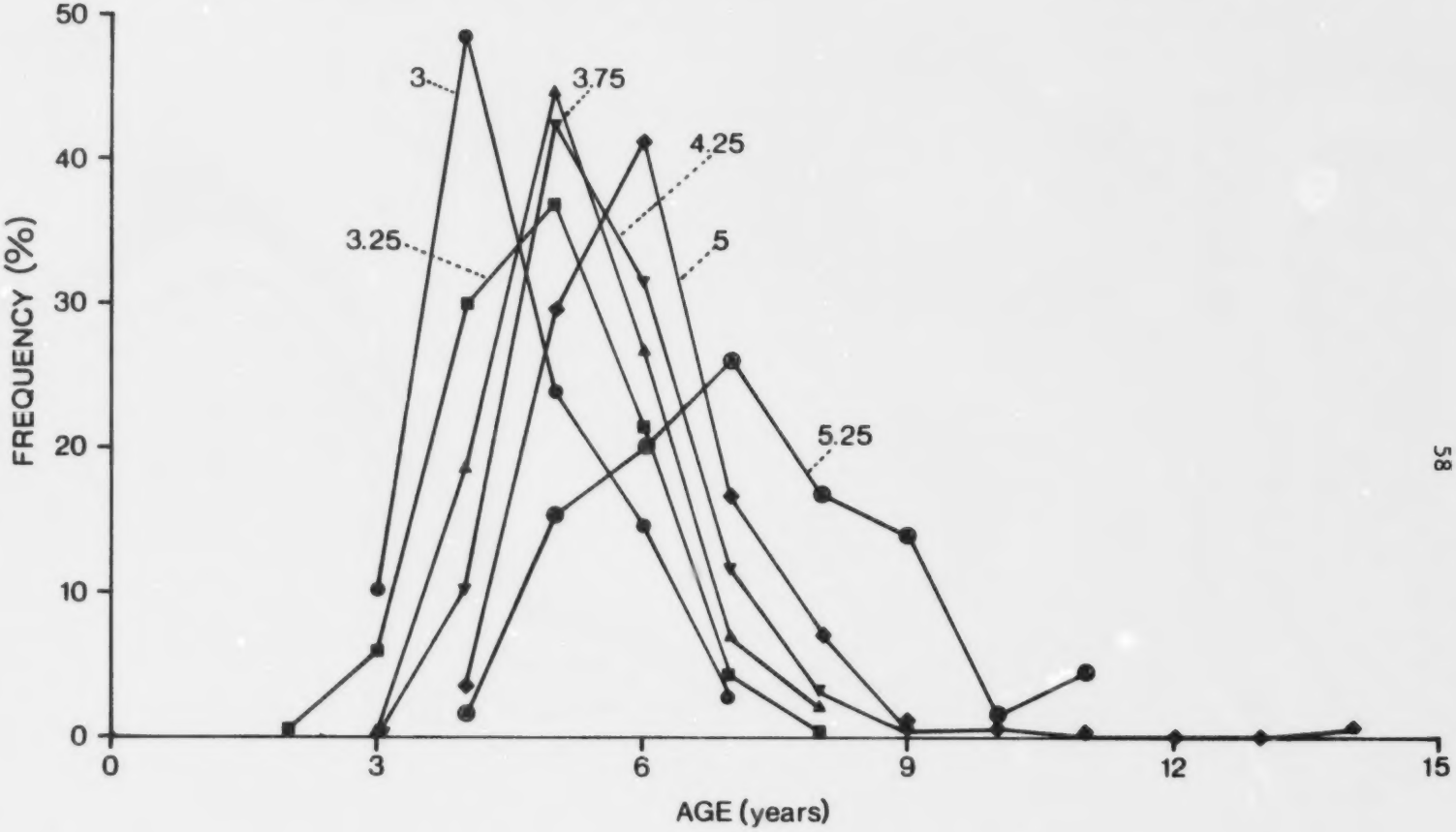

Fig. 30. Net selectivity with respect to ages of northern whitefish.

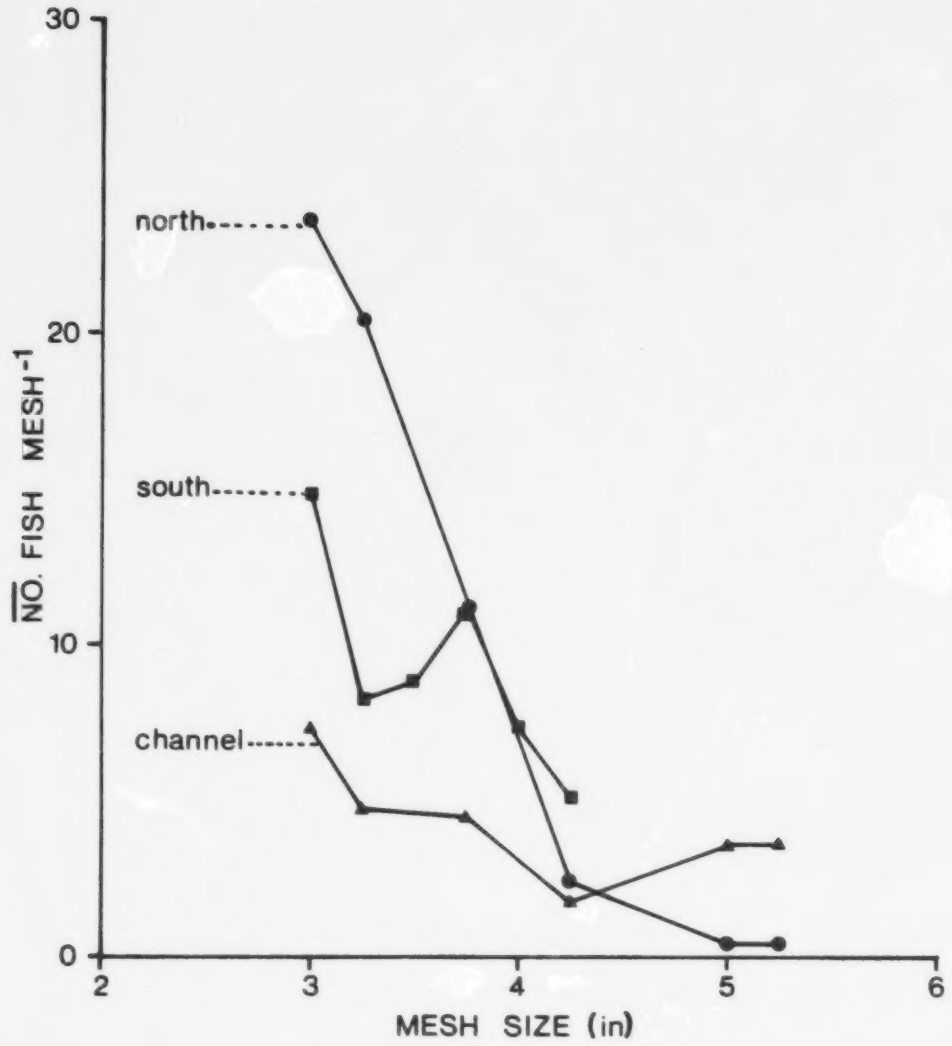

Fig. 31. Effects of mesh size on the mean numbers of saugers mesh^{-1} in the three major areas of Lake Winnipeg.

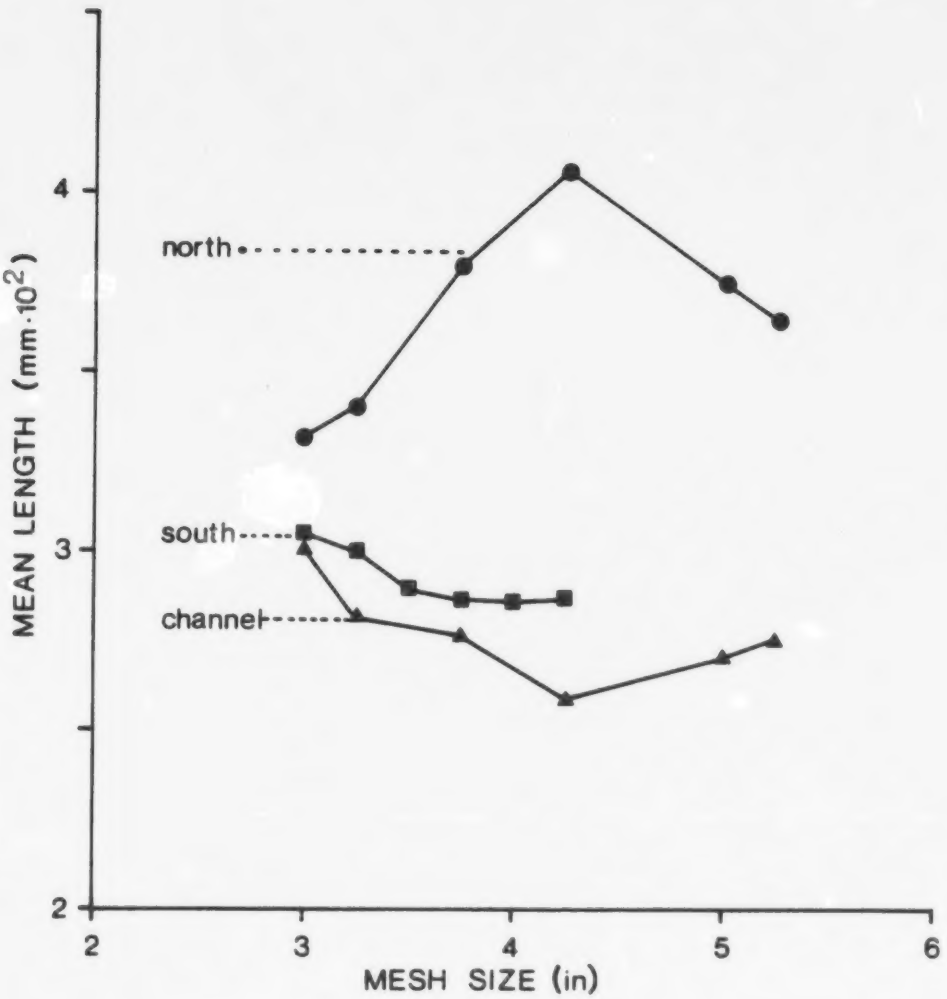

Fig. 32. The relationship of mean lengths of saugers and mesh sizes in the three major areas of Lake Winnipeg.

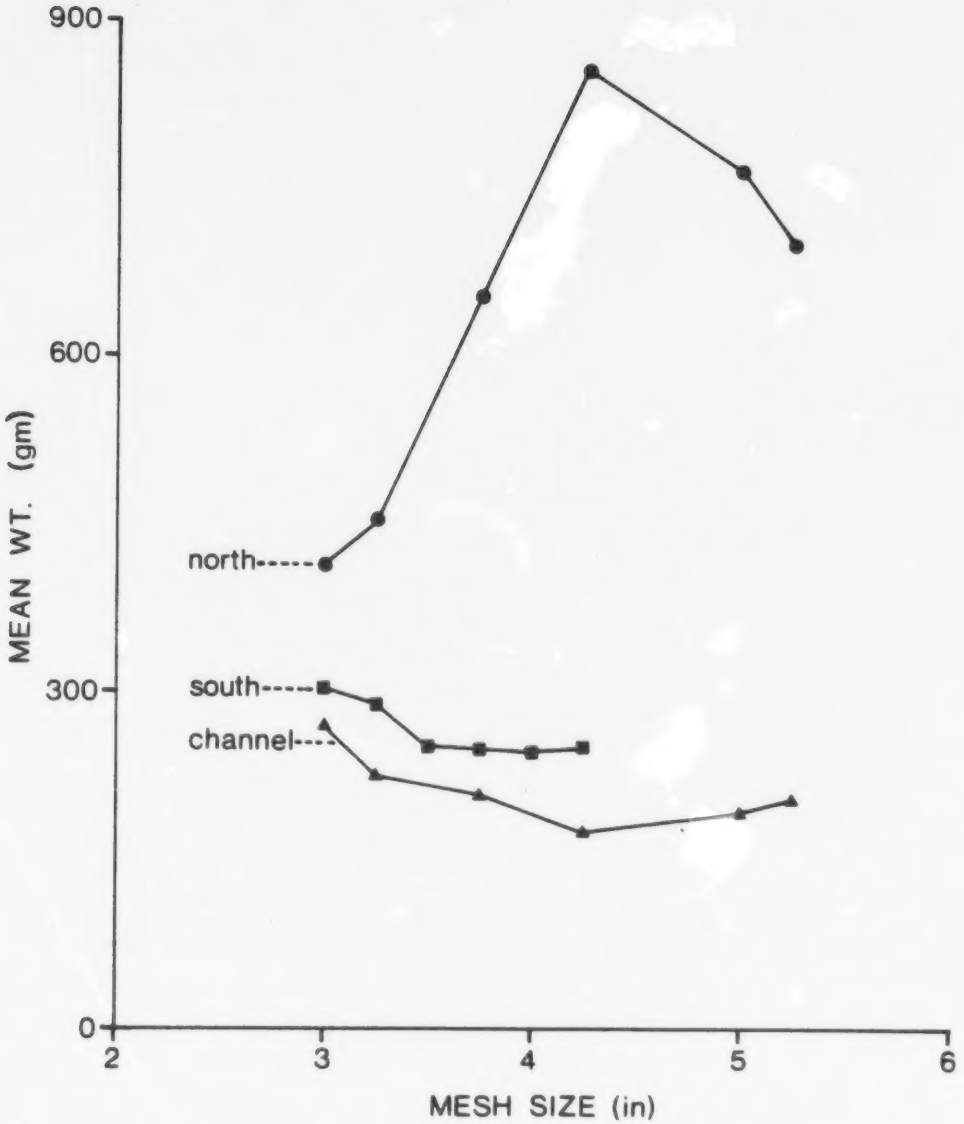

Fig. 33. The relationship of mean weights of saugers and mesh sizes in the three major areas of Lake Winnipeg.

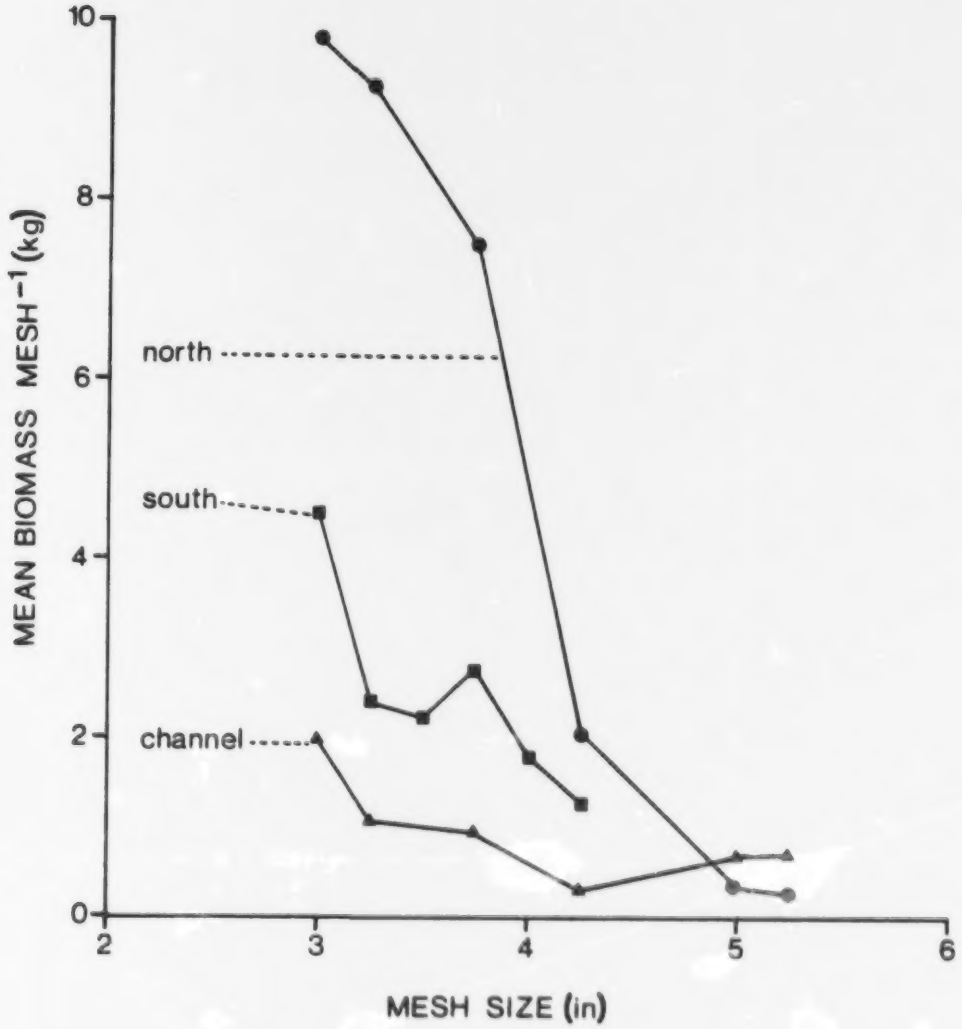

Fig. 34. Changes in the mean biomass of saugers per mesh over a range of meshes in the three major areas of Lake Winnipeg.

the channel and south basins. Frequencies of immature saugers caught in all meshes in the channel and south basins were at least five orders of magnitude greater than in the north basin (Fig. 35).

Mean numbers of southern walleyes per mesh decreased faster with increasing mesh size than northern walleyes.

Conversely, mean weights of northern walleyes increased faster with increasing mesh size than southern walleyes. The 3.75 inch mesh caught the heaviest walleyes in the south end (Fig. 36). Mean weights of northern walleyes in meshes larger than 3 inches were consistently greater than those of their southern counterparts. In meshes larger than 3.25 inches, mean lengths of northern walleyes were greater than mean lengths of southern walleyes (Fig. 37). The mean biomass per mesh of southern walleyes was equal to or greater than the northern walleye biomass per mesh in small meshes but decreased faster with increasing mesh size than the northern walleye biomass (Fig. 38).

The frequencies of immature northern walleyes decreased rapidly with increasing mesh size while the frequencies of immature southern walleyes increased with increasing mesh size (Fig. 39).

Mean lengths and weights of northern whitefish increased regularly with increasing mesh size (Figs. 40, 41). The mean biomass of whitefish increased rapidly from the 3 inch mesh to the 3.75 inch mesh and thereafter decreased regularly (Fig. 42). Frequencies of immature whitefish decreased regularly with increasing mesh size. The largest mesh still caught a small proportion of immature whitefish (Fig. 43, Appendix C).

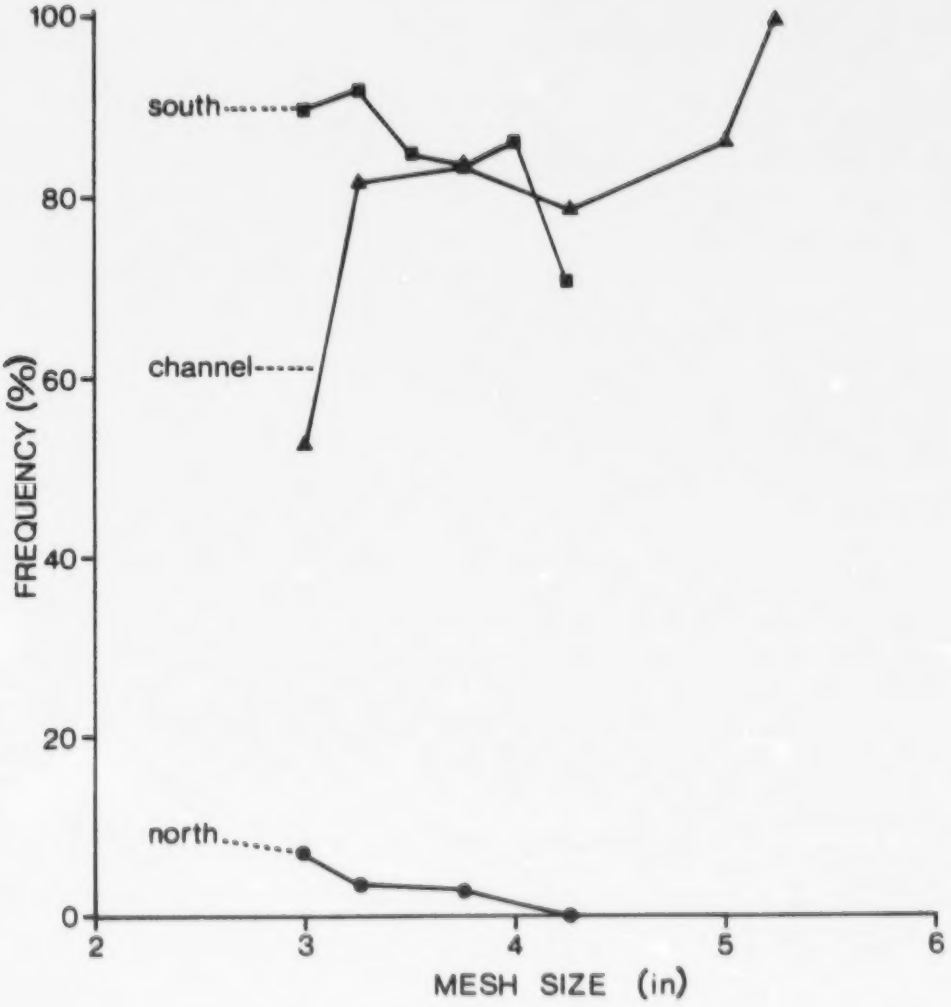

Fig. 35. Changes in frequencies of immature saugers in relation to mesh size in the three major areas of Lake Winnipeg.

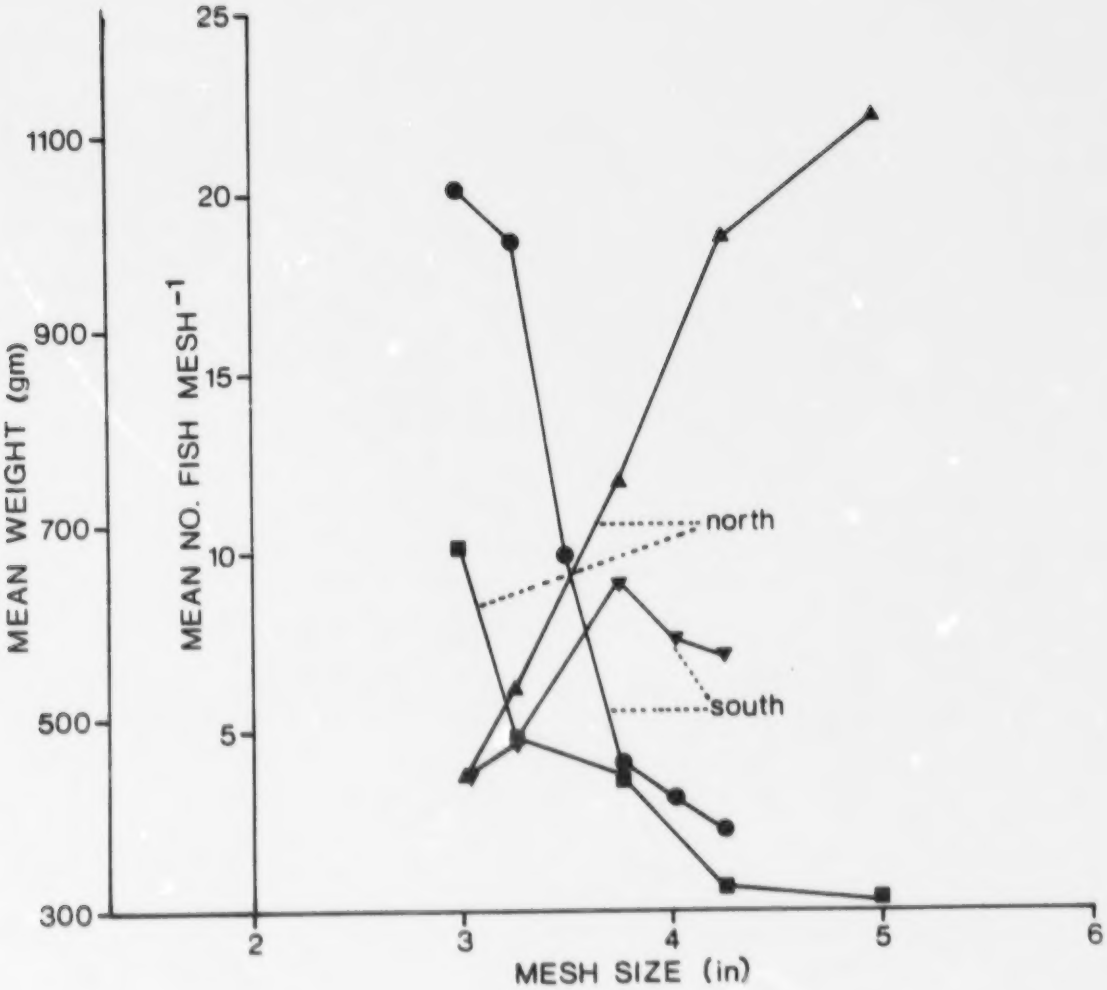

Fig. 36. Changes in mean numbers (● , ■) and mean weights (▲ , ▼) of northern and southern walleyes in relation to mesh size.

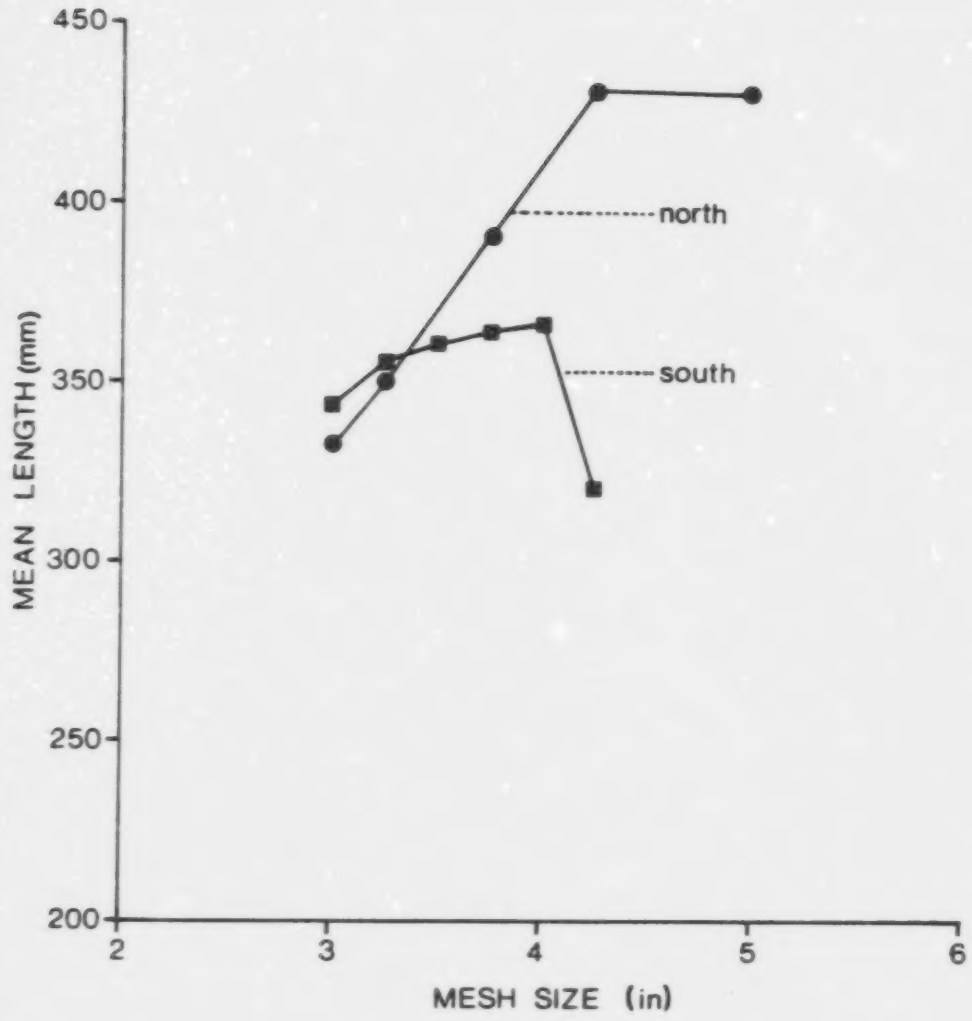

Fig. 37. Changes in mean lengths of northern and southern walleyes in relation to mesh size.

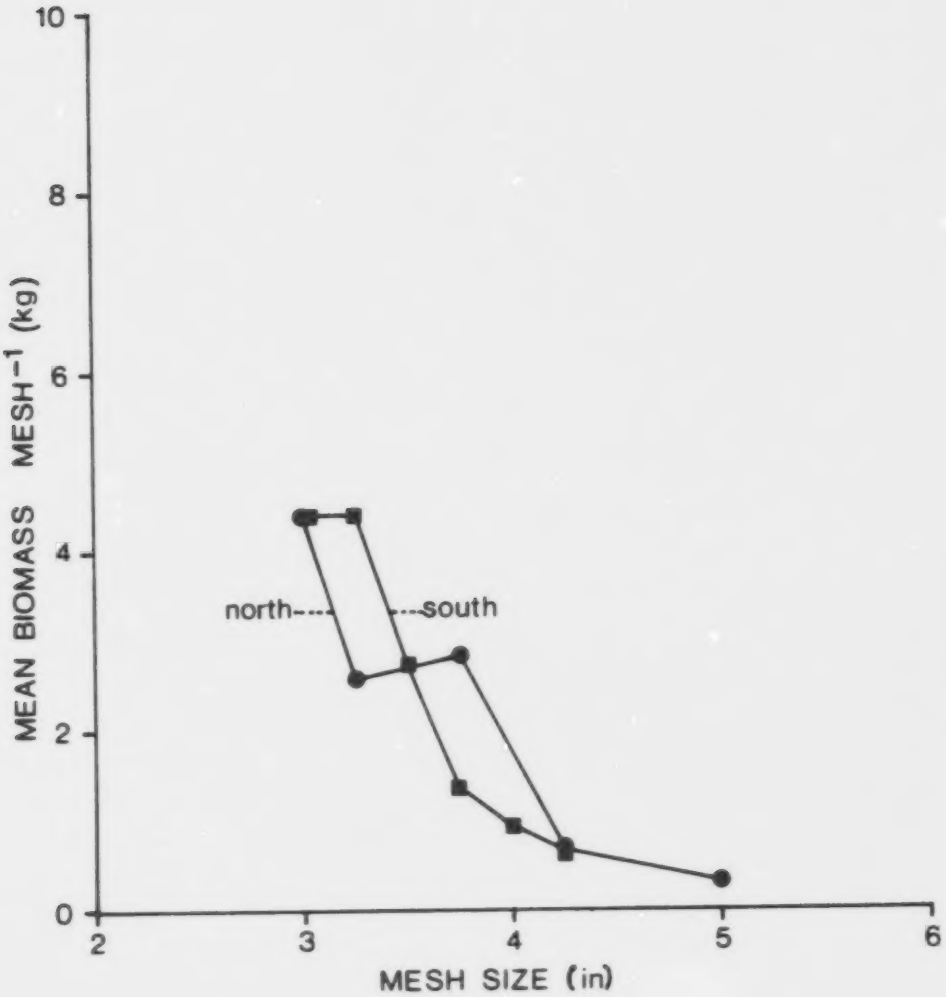

Fig. 38. Changes in mean biomass of walleyes per mesh in relation to mesh size in the north and south basins.

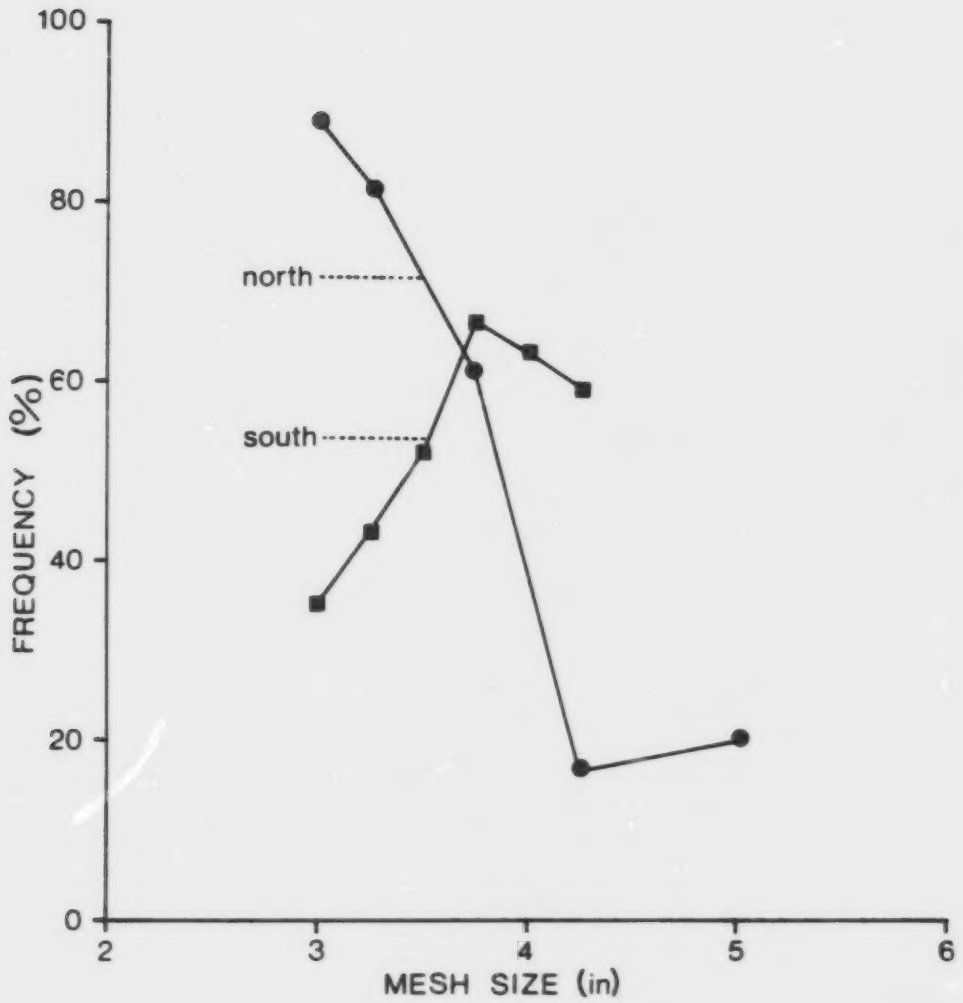

Fig. 39. Changes in frequencies of immature walleyes in relation to mesh size in the northern and southern basins.

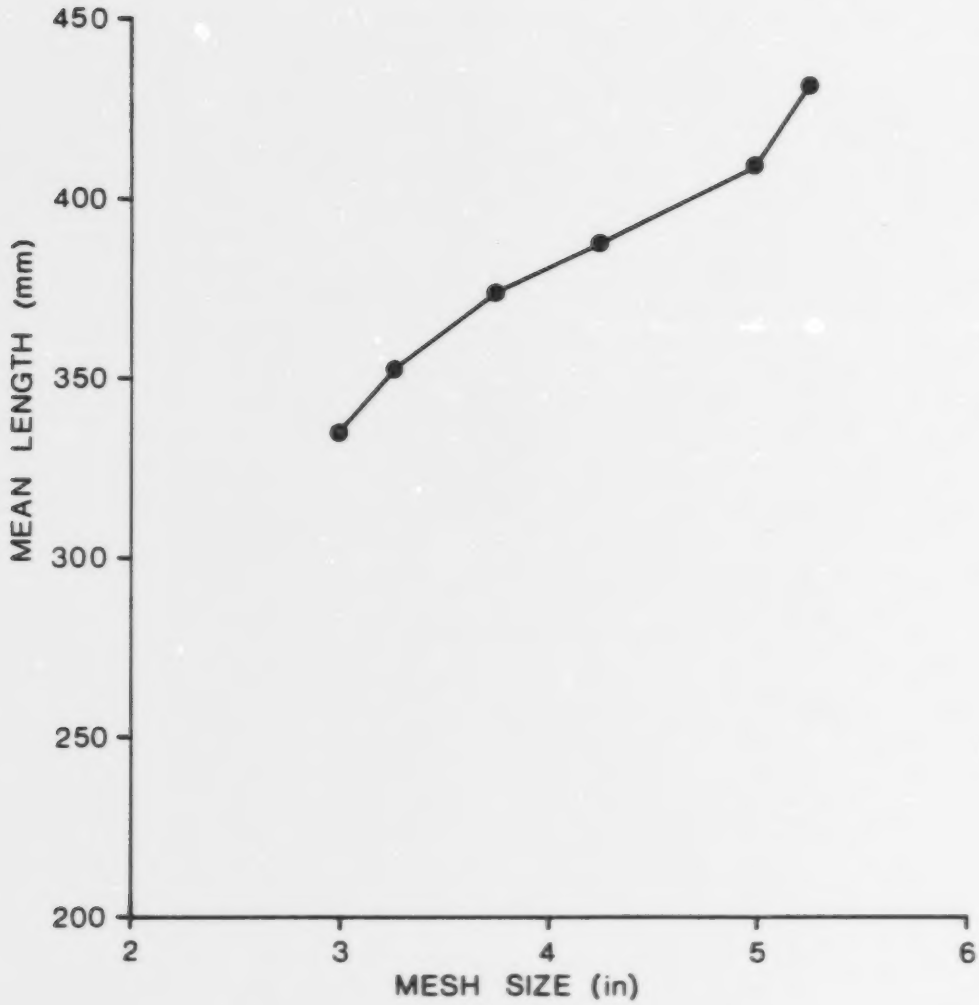

Fig. 40. Changes in mean lengths of northern whitefish in relation to mesh size.

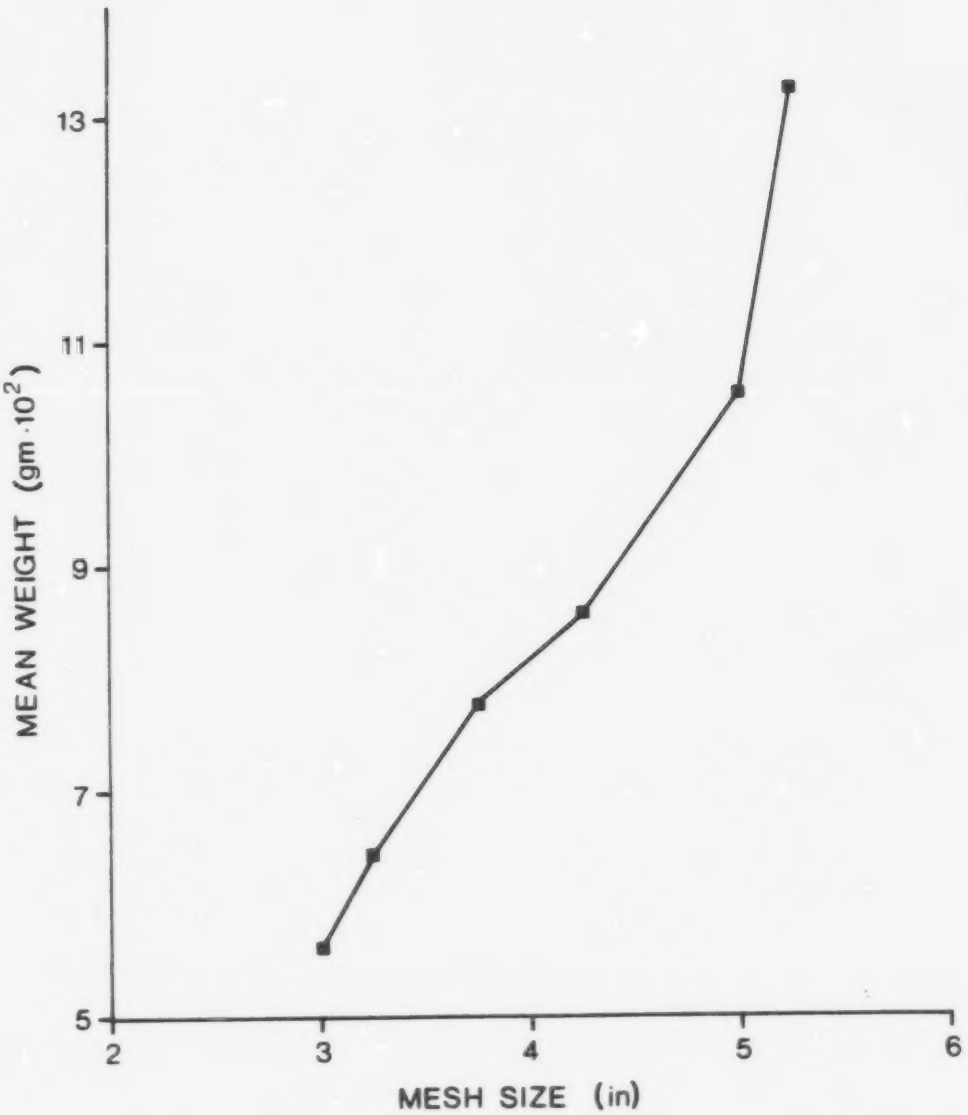

Fig. 41. Changes in mean weights of northern whitefish in relation to mesh size.

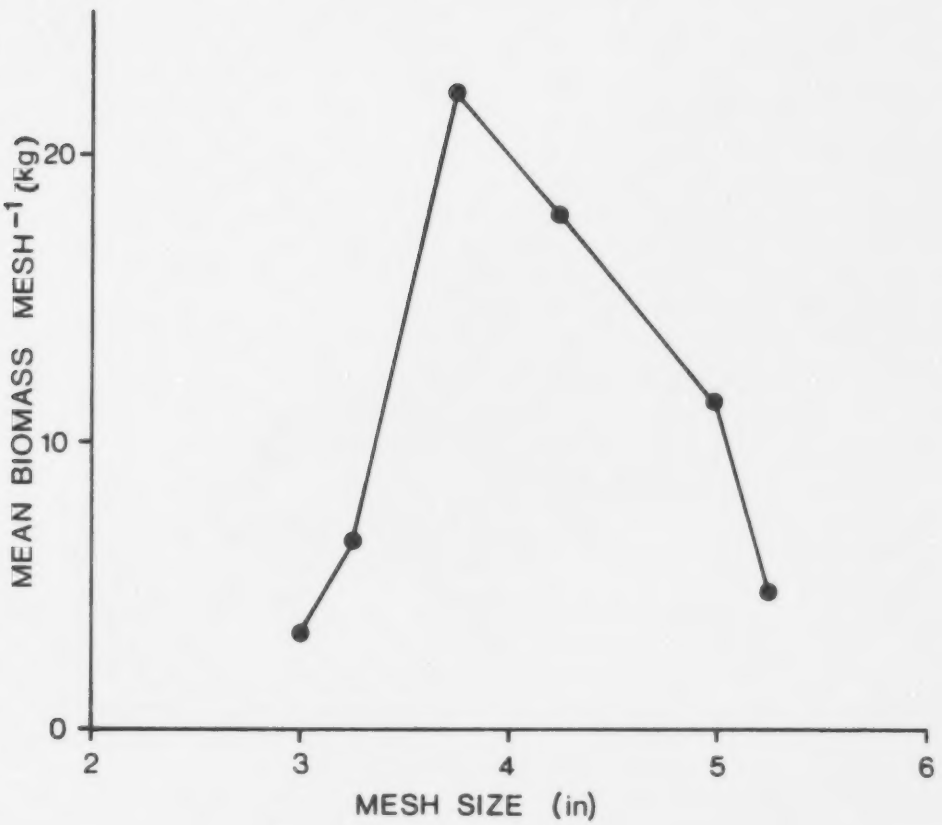

Fig. 42. Changes in mean biomass of whitefish per mesh in relation to mesh size.

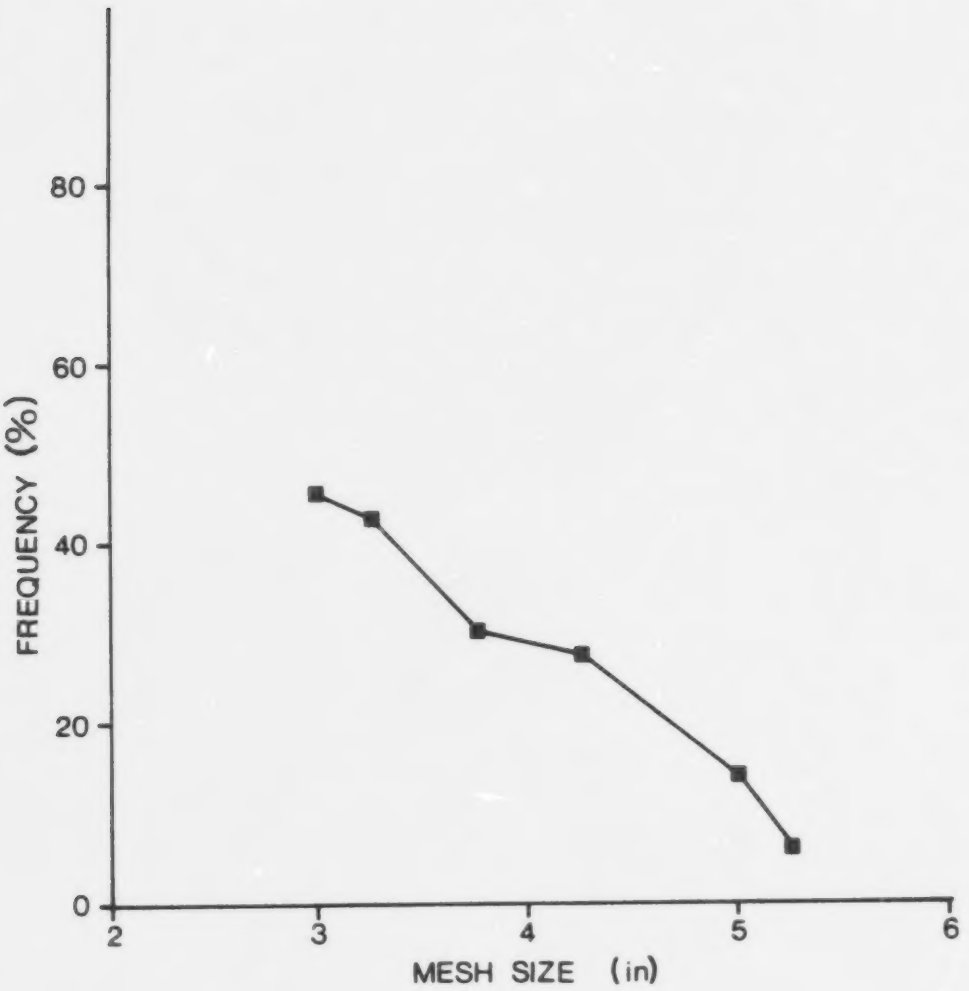

Fig. 43. Changes in frequencies of immature whitefish in relation to mesh size.

Table 20. Mortality rates of commercially caught species from the three major areas of Lake Winnipeg during the summer and fall fishing seasons.

Season	Species	Area																	
		North						Channel						South					
		Robson-Chapman			Regression			Robson-Chapman			Regression			Robson-Chapman			Regression		
		Z	A	S ± 2 S.E.	Z	A	S	Z	A	S ± 2 S.E.	Z	A	S	Z	A	S ± 2 S.E.	Z	A	S
Summer	Walleye	1.74	0.8245	0.1748 ± 0.2720	1.319	0.7329	0.2671	1.56	0.7899	0.2105 ± 0.1916	0.518	0.4055	0.5945	1.62	0.8021	0.1985 ± 0.1712	0.588	0.4457	0.5543
	Sauger	1.09	0.6638	0.3367 ± 0.1479	0.915	0.6015	0.3985	1.54	0.7856	0.2145 ± 0.1056	1.567	0.7878	0.2122	0.90	0.5934	0.4056 ± 0.1218	0.761	0.5323	0.4677
	Whitefish	1.15	0.6834	0.3163 ± 0.1023	0.819	0.5596	0.4404	0.89	0.5893	0.4111 ± 0.1101	0.656	0.4831	0.5169	-	-	-	-	-	-
Fall	Walleye	1.08	0.6604	0.3396 ± 0.1047*	1.018	0.6394	0.3606	0.78	0.5416	0.4578 ± 0.1303[1]	0.542	0.4173	0.5827	1.11	0.6704	0.3315 ± 0.2088	0.840	0.5683	0.4317
	Sauger	1.38	0.7484	0.2518 ± 0.1218	1.584	0.7941	0.2060	1.99	0.8633	0.1368 ± 0.1051	1.745	0.8262	0.1738	2.73	0.9348	0.0654 ± 0.0623 *	2.987	0.9497	0.0503
	Whitefish	1.33	0.7355	0.2639 ± 0.1350	1.170	0.6896	0.3104							-	-	-	-	-	-

*model age used in calculation

[1]two peaks were present in the catch curve

Commercial sampling

The mean weighted ages derived from commercial age compositions generally indicate that the south basin and channel fisheries catch younger fish than the north basin fishery both in the summer and fall season (Table 19). This trend is paralleled by decreasing mean sizes in the fall fisheries but is not paralleled by size changes in the summer fisheries (Table 19). Age compositions of saugers and walleyes sampled from the summer and fall fisheries (Figs. 44 - 47) and whitefish sampled from the summer fishery (Fig. 48) were used to derive catch curves (Figs. 49 - 53). Differences between walleye survival rates from the north and south basins were not significant for the summer and fall fisheries (Table 20). Annual mortality rates of both northern and southern walleyes were lower in the fall than in summer. Differences between northern and southern sauger survival rates were not significant during the summer. Annual mortality rates of saugers increased dramatically during the fall season in both the north and south basins (Table 20). Differences in whitefish survival rates between the summer and fall fisheries were not significant (Table 20).

During the summer season, catch curves of northern and channel saugers were convex while the southern sauger catch curve was concave (Fig. 49). In autumn, the channel sauger catch curve also became concave (Fig. 50). During the summer season, catch curves of southern channel walleyes were irregularly shaped while the northern walleye catch curve indicated heavy exploitation of older fish (Fig. 51). In

Table 19. Age compositions of commercially caught species from the three major areas of Lake Winnipeg during the summer and fall fishing seasons.

Season	Age (years)	Species															
		Walleye						Sauger						Whitefish			
		North		Channel		South		North		Channel		South		North		Channel	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Summer	2	1	0.08			2	0.30							1	0.04		
	3	3	0.25	19	18.10	205	31.20					4	0.66	4	0.16	1	0.20
	4	30	2.49	27	25.71	123	18.72	9	3.57	37	7.14	67	11.00	123	4.96	28	5.74
	5	182	15.12	35	33.33	100	15.22	62	24.60	223	43.05	296	48.60	976	39.34	223	45.70
	6	377	31.31	4	3.81	95	14.46	104	41.27	199	38.42	151	24.79	954	38.45	146	29.92
	7	531	44.10	15	14.29	97	14.76	50	19.84	50	9.65	48	7.88	313	12.62	53	10.86
	8	69	5.73	4	3.81	16	2.44	19	7.54	9	1.74	22	3.61	66	2.66	13	2.66
	9	6	0.50			3	0.46	7	2.78			15	2.46	13	0.52	8	1.64
	10	4	0.33			2	0.30	1	0.40			6	0.99	14	0.56	7	1.43
	11	1	0.08											8	0.32	2	0.41
	12					1	0.15							5	0.20	4	0.82
	13													2	0.08		
	14													1	0.04		
	15													1	0.04		
	$\bar{L}$	425.62		373.10		389.16		329.45		299.25		316.44		404.80		402.55	
	$\bar{W}$	951.55		673.14		768.53		403.25		296.66		407.36		873.93		953.69	
	$\bar{A}$	6.38		4.77		4.64		6.13		5.56		5.54		4.97		5.72	
Fall	2			1	0.22	8	0.80	6	2.41	2	0.40	11	1.51	7	2.81		
	3			29	6.50	413	41.39	50	20.08	52	10.40	288	39.45	43	17.27		
	4	10	4.02	70	15.70	436	43.64	92	36.95	258	51.60	402	55.07	114	45.78		
	5	87	34.94	166	37.22	101	10.11	71	28.51	164	32.80	28	3.84	62	24.90		
	6	92	36.95	74	16.59	22	2.20	27	10.84	19	3.80	1	0.14	16	6.43		
	7	48	19.28	80	17.94	10	1.00	2	0.80	5	1.00			3	1.20		
	8	11	4.42	25	5.61	4	0.40	1	0.40								
	9	1	0.40			3	0.30										
	10													1	0.40		
	11					1	0.10							1	0.40		

Table 19. Continued

Season	Age (years)	Species											
		Walleye						Sauger				Whitefish	
		North		Channel		South		North		Channel		South		North		Channel	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
	12																
	13																
	14													1	0.40		
	$\bar{L}$	427.34		400.06		359.61		317.49		315.98		304.55		395.89			
	$\bar{W}$	1036.87		833.79		541.92		421.04		362.14		320.06		774.30			
	$\bar{A}$	5.86		5.39		3.78		5.29		5.32		4.62		5.24			

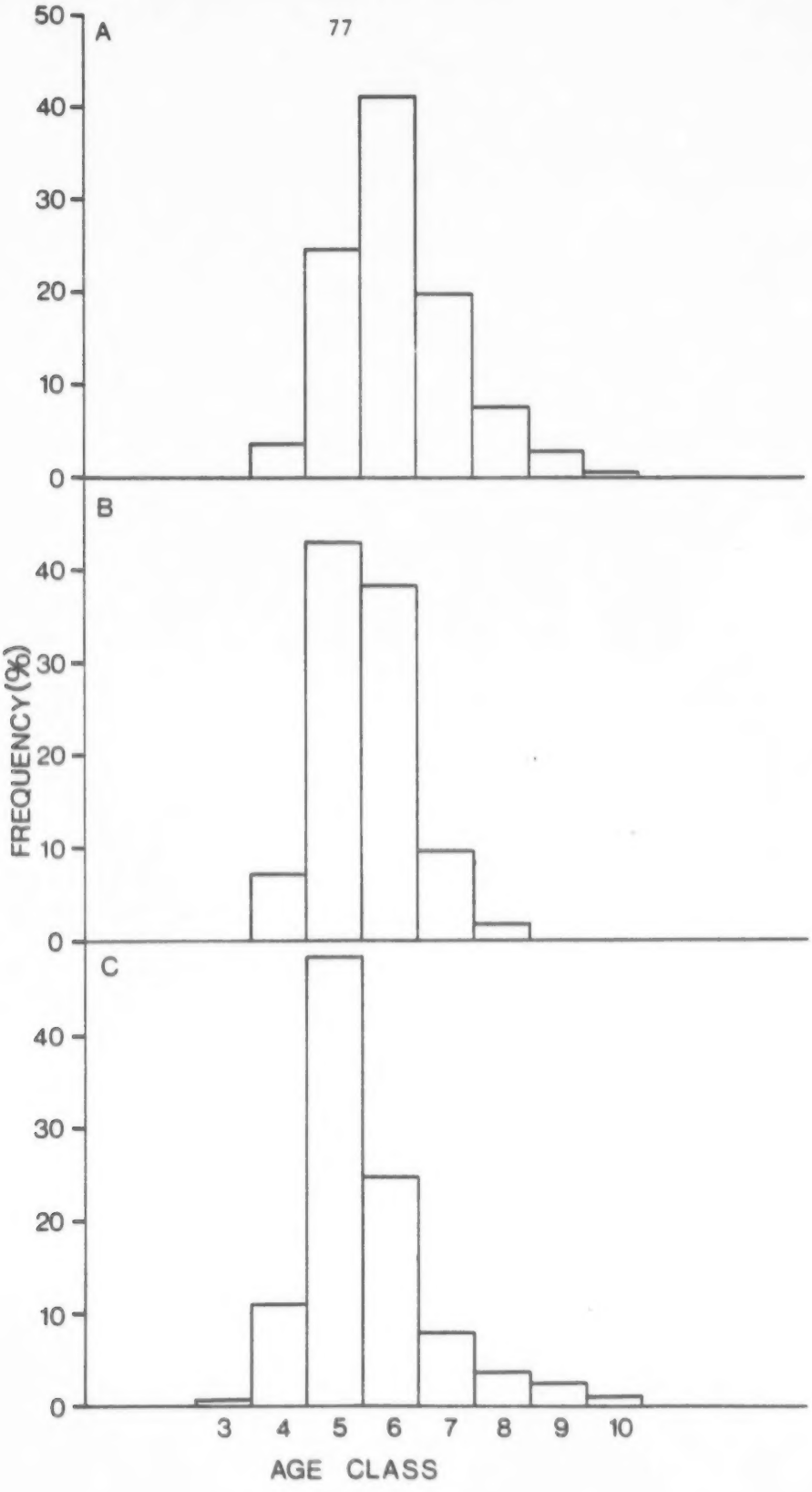

Fig. 44. Age compositions of commercially caught northern (A), channel (B) and southern (C) saugers from Lake Winnipeg, summer 1979.

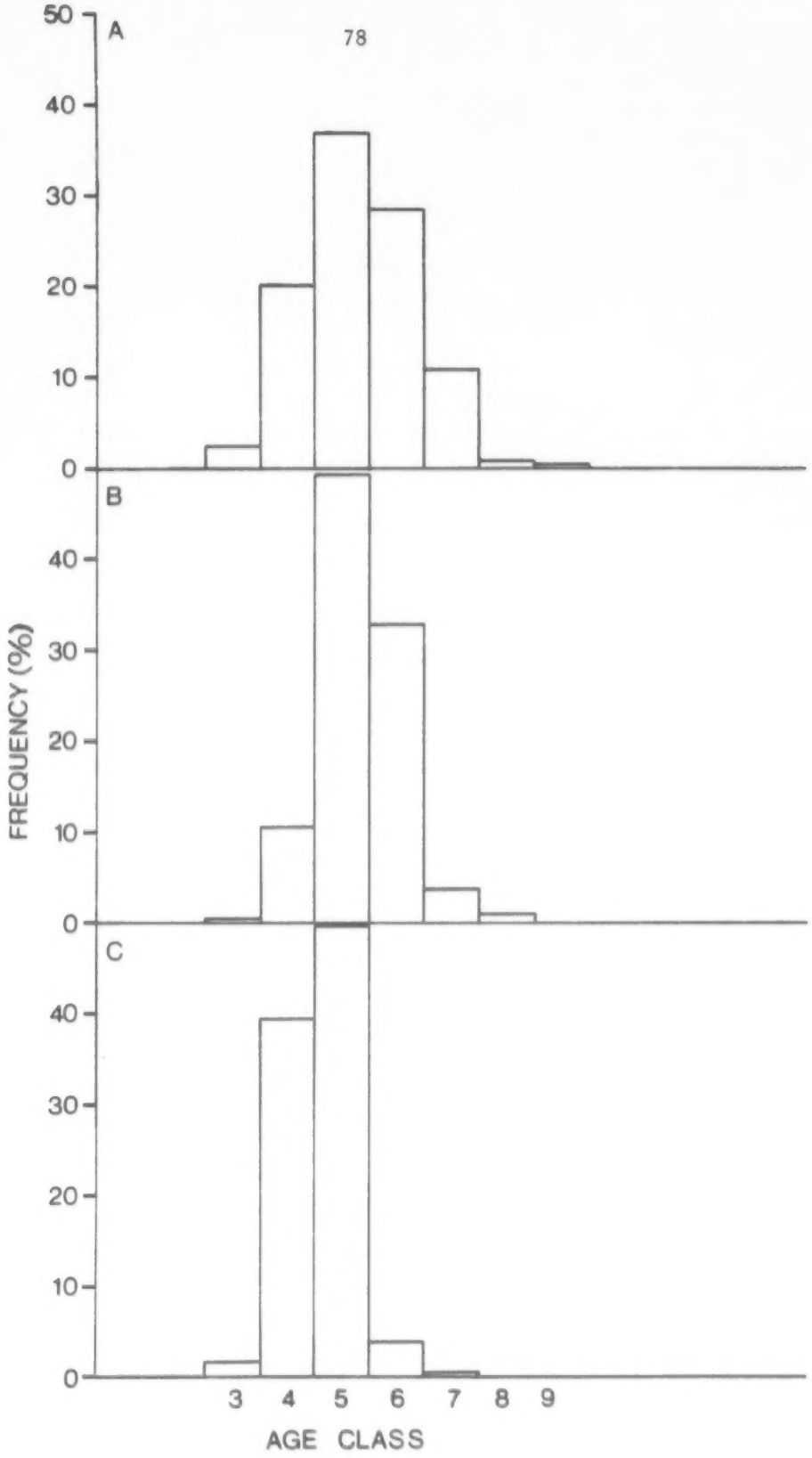

Fig. 45. Age compositions of commercially caught saugers from the northern (A), channel (B) and southern (C) areas of Lake Winnipeg, autumn 1979.

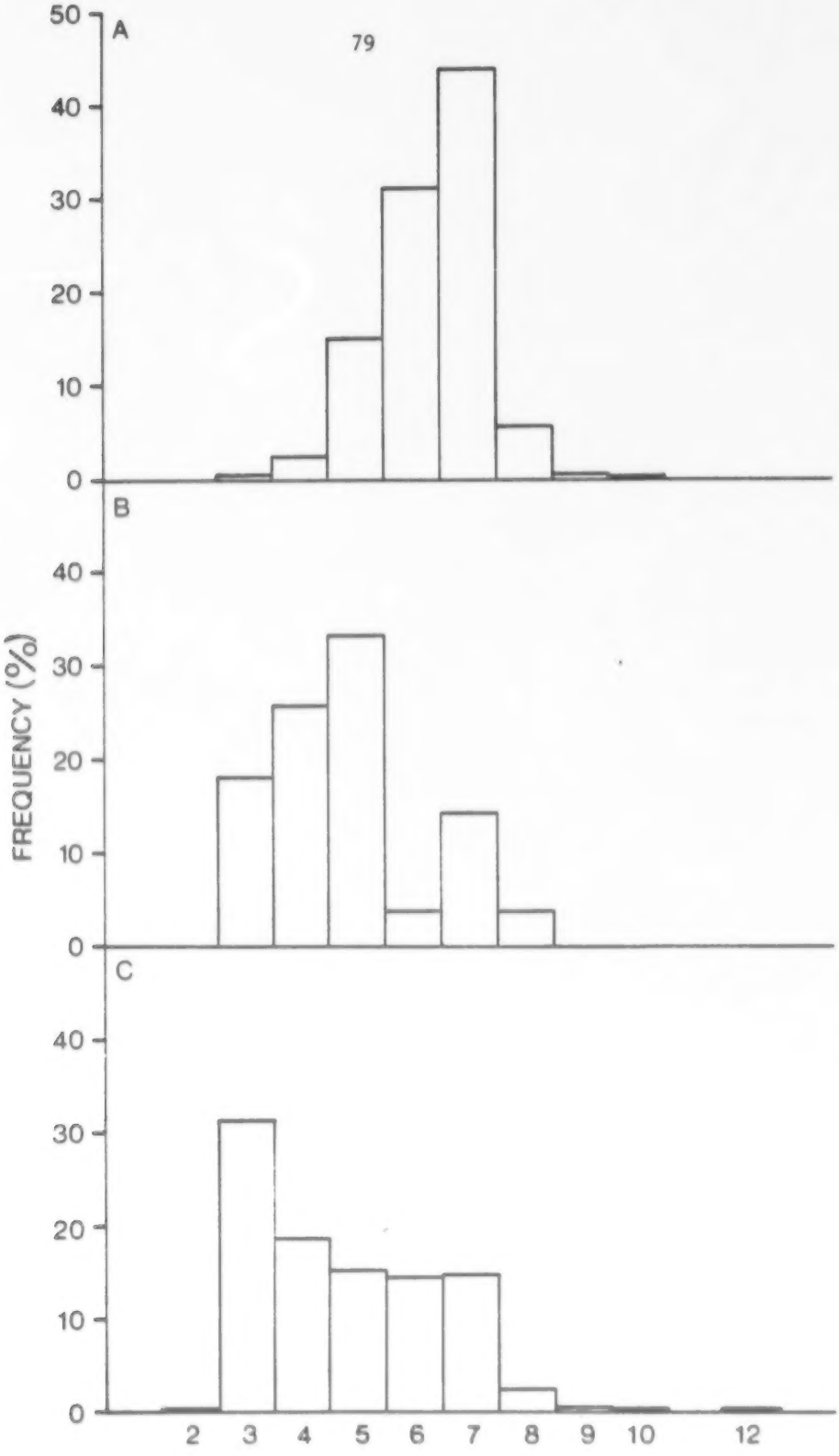

Fig. 46. Age compositons of commercially caught walleyes from the northern (A), channel (B) and southern (C) areas of Lake Winnipeg, summer 1979.

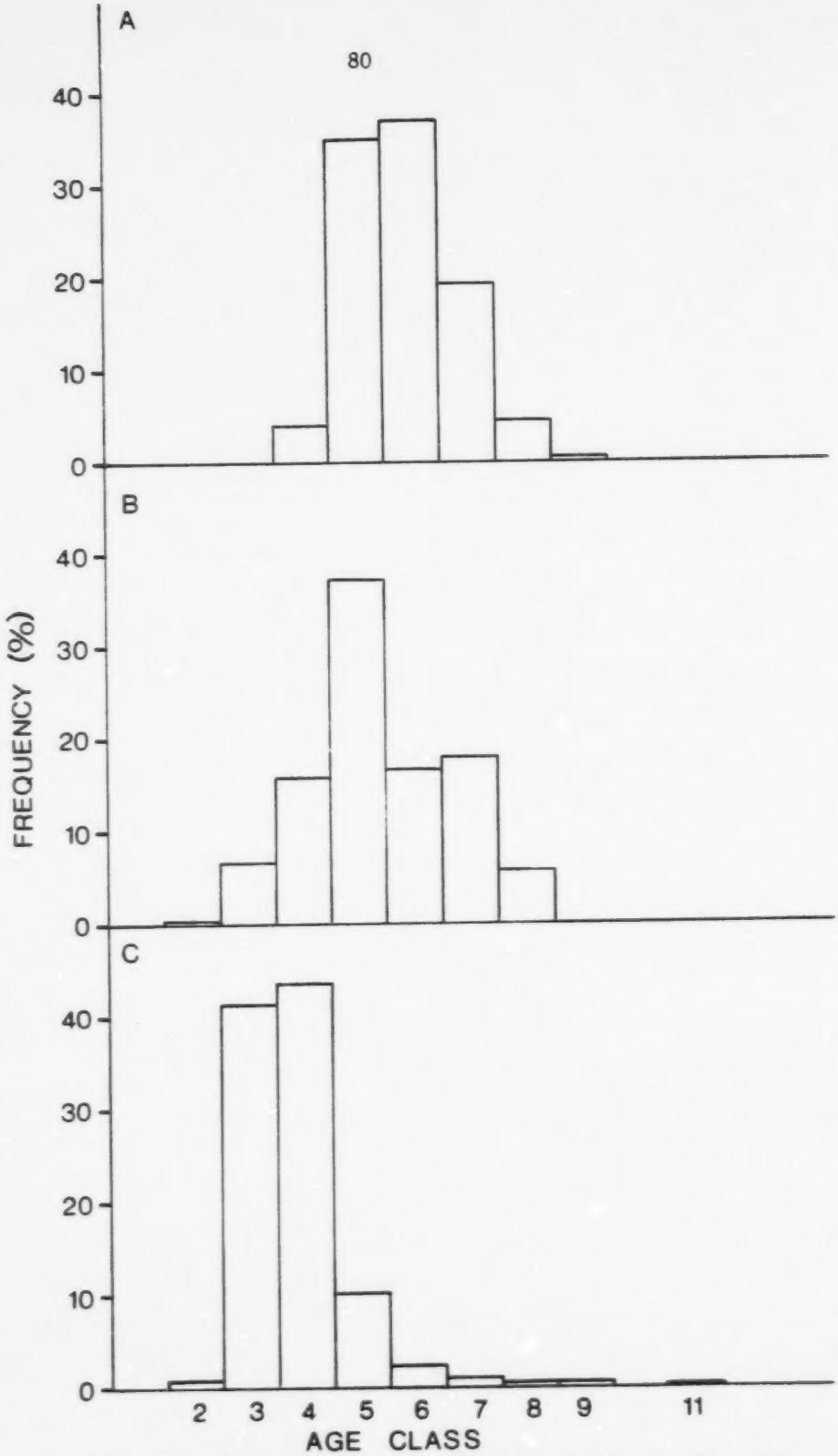

Fig. 47. Age compositions of commercially caught walleyes from northern (A), channel (B) and southern (C) areas of Lake Winnipeg, fall 1979.

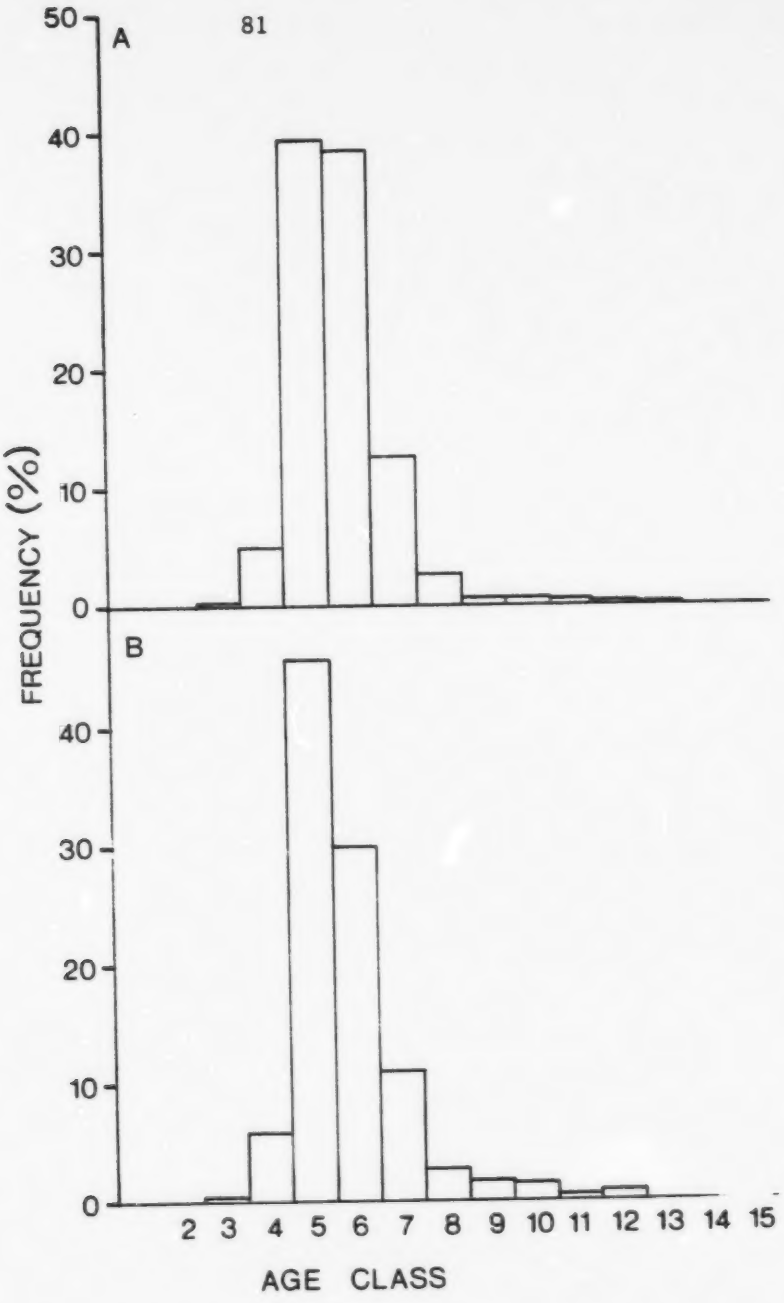

Fig. 48. Age compositions of commercially caught whitefish from the northern (A) and channel (B) areas of Lake Winnipeg, summer 1979.

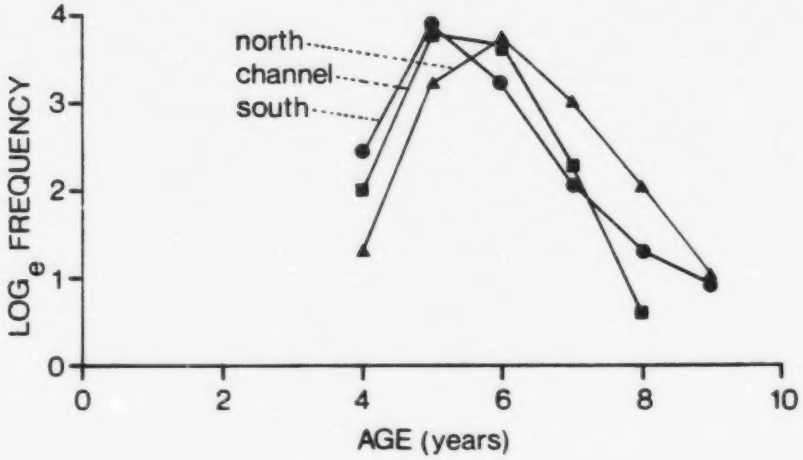

Fig. 49. Summer catch curves of commercially caught saugers from the northern, channel and southern areas of Lake Winnipeg, 1979.

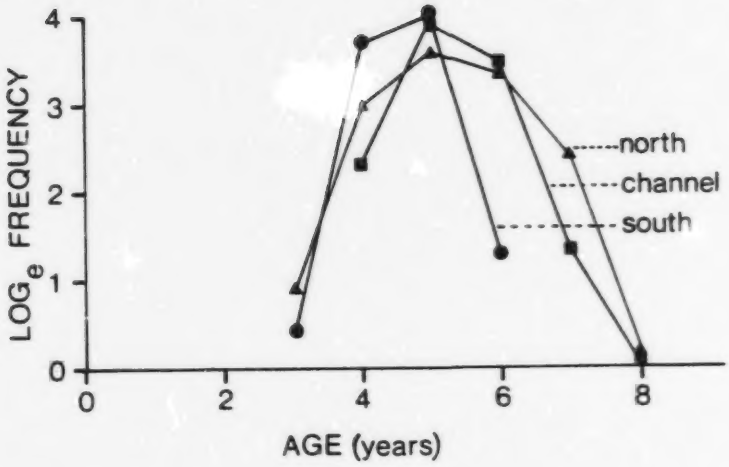

Fig. 50. Autumn catch curves of commercially caught saugers from the northern, channel and southern areas of Lake Winnipeg, 1979.

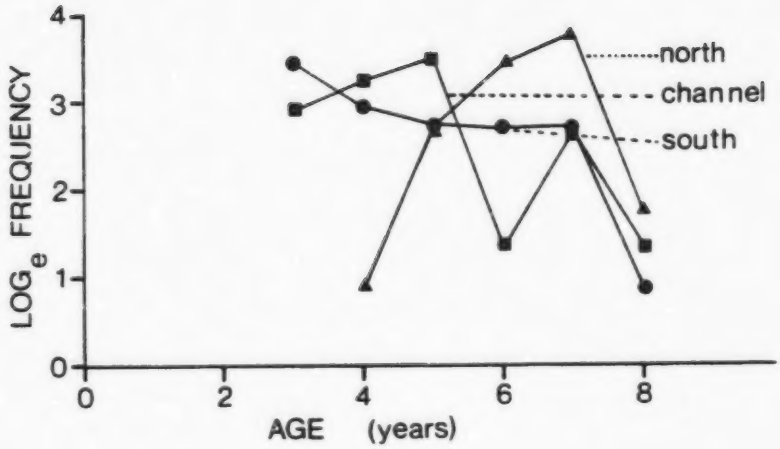

Fig. 51. Summer catch curves of commercially caught walleyes from the northern, channel and southern areas of Lake Winnipeg, 1979.

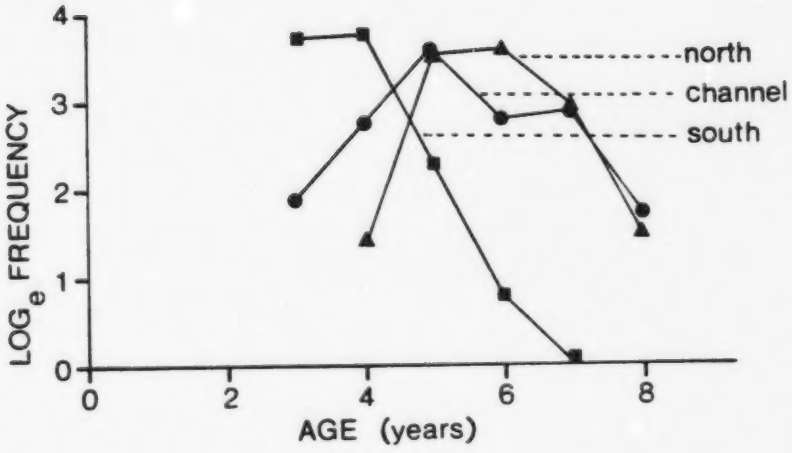

Fig. 52. Autumn catch curves of commercially caught walleyes from the northern, channel and southern areas of Lake Winnipeg, 1979.

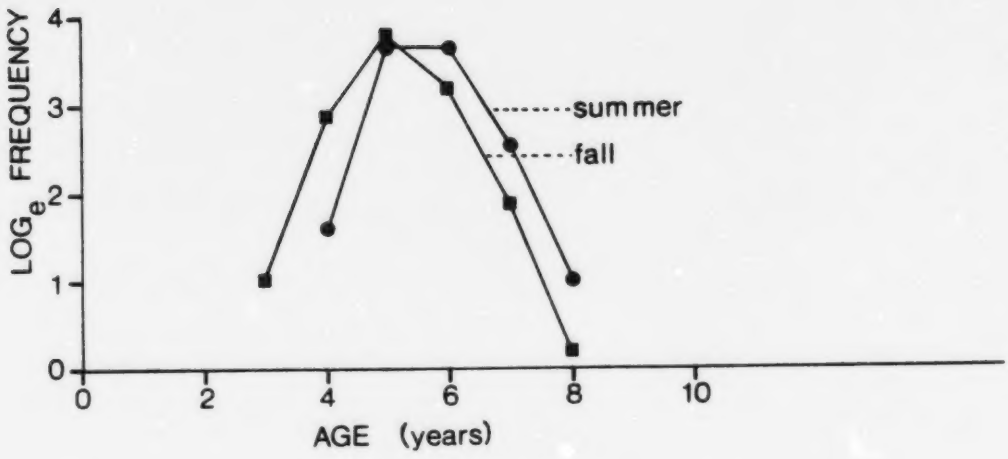

Fig. 53. Summer and fall 1979 catch curves of commercially caught whitefish from Lake Winnipeg.

autumn, the southern walleye catch curve showed an increase in mortality rate while the mortality rate of northern walleyes decreased (Fig. 52).

Abrasov's (1967) t index was negative for all species in all basins during both seasons except for the summer and fall southern sauger fisheries and the whitefish fishery (Table 21).

Table 21. Abrasov's (1967) t indices for walleyes, saugers and whitefish from the three major areas of Lake Winnipeg.

Species	Season	Area	Mean age of commercial catch (years)	Mean age of maturity (years)	t index (years)
Walleye	summer	north	6.38	7.85	-1.47
		south	4.64	5.39	-0.75
	fall	north	5.86	7.85	-1.99
		south	3.78	5.39	-1.61
Sauger	summer	north	6.13	6.44	-0.31
		south	5.54	2.78	2.76
	fall	north	5.29	6.44	-1.15
		south	4.62	2.78	1.84
Whitefish	summer	north	4.97	2.49	2.48

DISCUSSION

Experimental sampling

Species proportions

Estimates of the relative proportions of species (in terms of abundance) in the three major areas of Lake Winnipeg were subject to the compositions of gillnet gangs employed in this study. Since the southern gangs were composed of different meshes than the northern gangs, species proportions among the major areas are not directly comparable. In spite of this incongruity, certain spatial features of species proportions are evident:

a. Whitefish are more numerous in the north than in the channel and southern areas of Lake Winnipeg. Commercial fishermen are reporting a recent increase in the proportions of whitefish caught in the north channel area. This indicates that whitefish may be moving away from their traditional northern grounds.

b. Saugers were relatively more numerous than walleyes in the north and channel areas. Proportions of saugers and walleyes were equal in the south basin. These differences are at least partly attributable to differences among the minimum mesh sizes allowed in the commercial fisheries of the three major areas. Since the asymptotic size of saugers is smaller than that of walleyes, it follows that walleyes would be more vulnerable to the larger commercial meshes used in the north basin. This is not an issue in the southern basin since the mesh size is much smaller and catches both species at smaller sizes. Saugers and walleyes occupy similar niches and probably

compete for similar food and space in the south basin. Thus proportions of southern walleyes and saugers are fairly similar and dominance changes back and forth with time

c. The channel area contains high proportions of less desirable species such as suckers, burbot and carp. Since flows of water and boat traffic are concentrated in the channel, it is probable that static populations would not occur here.

Maturity regimes

Age-specific or size-specific frequencies of mature fish follow a logistic distribution. It is hypothesized that the slope and inflection point of such a maturity curve will increase as fishing effort increases because fish stocks respond to increases in fishing effort by maturing at a faster rate. Sex-specific differences in maturity rates occurred only among southern saugers. Sex did not affect maturity rates of walleyes and whitefish. Age-specific regressions of maturity frequencies were not significant for northern sauger males, northern whitefish females and southern walleye males. Regressions of female walleyes and saugers were significant in both northern and southern basins. However, differences in maturity rates between basins were not significant, i.e. fishery effects on maturity rates are negligible. Attempts to estimate maturity rates of walleyes and saugers and to relate these rates to fishery effects in the north and south basins failed due to three important factors:

a. the frequencies of mature fish in the youngest age classes could not be estimated since the smallest mesh in

the experimental gang was too large to catch the youngest fish. The frequency of mature fish in the youngest age classes that were vulnerable to the gear was probably overestimated due to gear selectivity of the fastest growing (and therefore fastest maturing) fish.

b. Visual determination of maurity categories in autumn on the south basin produces non-significant maturity curves. Olynyk (pers. comm.) found that visual determinations of walleye and sauger maturity frequencies yielded statistically significant maturity curves in spring. Also, substantial discrepancies between visual and histological determinations of maturity occurred. Visual determinations of maturity were subject to differences among field personnel.

c. The use of a "developing" maturity category precluded the use of strictly mature fish in fitting southern maturity curves. The use of this category resulted in irregular distributions of mature fish over a range of ages instead of the more usual logistic distribution.

Attempts to model size-specific frequencies of mature fish were confounded by the subjectivity of an arbitrarily chosen length interval. Probit analysis would provide a more objective choice of a length interval.

Abrasov's (1967) formula estimates the mean weighted age of onset of sexual maturity. This estimate becomes crude when few young and few old fish are sampled and when sampled proportions of mature fish in younger age classes (i.e. where $A_{n+1}(K_{n+1} - K_n) \leq A_n(K_n - K_{n-1})$. The use of a fitted maturity curve eliminates problems caused by

negative A_n ($K_n - K_{n-1}$) values. Also, the use of fitted maturity curves in monitoring year-to-year changes in maturity rates in much more sensitive to changes in fishing effort than Abrosov's Z value. Z may remain relatively static while the instantaneous maturity rate may change significantly. In spite of these shortcomings, Abrasov's estimates of the mean age of maturity of Lake Winnipeg walleyes and saugers indicate that southern stocks mature faster than northern stocks.

Age compositions, catch curves and mortality rates

The experimental northern walleye catch curve was more convex than its southern counterpart and its peak was 1.2 years older than the peak of the southern walleye catch curve. However, mortality rates (estimated by regression and the Robson-Chapman (1961) formula) of southern and northern walleye stocks were not significantly different. Southern and channel walleye catch curves derived from commercial samples deviated from the classical form. These curves indicate that five and seven year old walleyes contributed heavily to fishermen's catches in summer. Anomalies in these catch curves were probably caused by non-random sampling of commercial catches from the southern and channel areas. In autumn, southern fishermen caught fewer five to seven year old walleyes but caught more three and four year old walleyes. Differences between walleye survival rates from the north and south basins were not significant for summer and fall fisheries. Annual mortality rates of both northern and southern walleye decreased from summer to fall.

Conversely, mortality rates of saugers increased dramatically from summer to fall. In summer, commercial catch curves of northern and channel saugers were convex while the southern sauger catch curve also became concave and mortality rates of both channel and southern saugers increased. These trends indicate that fishing pressure is heavier in the channel and southern areas than in the north basin and that fishing pressure increases from summer to fall in these areas.

The experimental whitefish catch curve was slightly concave. Experimental mortality rates of whitefish estimates by regression and the Robson-Chapman method were not significantly different. The regression estimate of commercial whitefish mortality was significantly higher than the Robson-Chapman estimate. Experimental and commercial whitefish mortality estimates by the Robson-Chapman method were almost identical. Davidoff et al. (1973) reported that the annual survival rate of Lake Winnipeg whitefish rose steadily from 3% to 54% from 1971 to 1977. In 1979, the annual survival rate of commercially caught whitefish was 32% to 44%. This indicates that either fishing pressure has increased or strong cohorts have passed through the fishery.

Growth regimes

Assuming that various growth parameters will change to compensate for changes in fishing effort, the following differences between growth patterns of northern and southern walleye and sauger stocks indicate that fishing pressure is too high in the southern part of the lake:

a. slopes of northern walleye and sauger length - weight

curves were significantly higher than these of their southern counterparts. Northern walleye and sauger growth is positively allometric while southern walleye and sauger growth is negatively allometric. Hanford et al. (1977) suggest that since gillnets remove large, proportionately fat fish, selective pressures operate to favour proportionately thinner fish.

b. asymptotic size of northern walleyes and saugers were larger than those of southern walleyes and saugers. Since smaller commercial meshes are allowed in the south basin, they crop smaller saugers and walleyes. Larger commercial meshes in the north basin allow fish to attain larger asymptotic sizes because they are recruited to the fishery at a larger body size.

c. two independent estimates of growth rates indicate that southern stocks grow faster than northern stocks. Growth of southern stocks is highly accelerated in compensatory response to heavy fishing pressure. Larger minimum mesh sizes and relatively lighter fishing pressures in the channel and northern areas of the lake allow fish to attain larger sizes before they are recruited to commercial nets. Since fishing pressure is lighter, compensatory increases in growth rates of pre-recruited channel and northern stocks are not as evident as they are in the south basin.

Net selectivity

With respect to sauger age classes, net selectivity of the experimental gang was greatest in the north basin, less in

the channel and non-existent in the south basin. This pattern is a function of minimum commercial mesh sizes allowed in the three major areas of the lake. Since the smallest mesh of the experimental gang was the same size as the legal minimum mesh allowed in the south basin, no net selectivity occurred in the south basin. Larger legal minimum meshes in the northern parts of the lake allowed a larger range of pre-recruited fish to be caught by the experimental gangs. Net selectivity with respect to walleye age classes was also more pronounced in the north than in the south basin.

Mesh size effects

Analyses of mean numbers, mean lengths and mean weights of walleyes and saugers caught over a range of experimental meshes produced less comprehensive patterns than mean biomass mesh^{-1} over a range of mesh sizes. It is evident that use of a large minimum commercial mesh size in the north basin is protecting a large, pre-recruited fraction of the stocks. This large portion of the total biomass is required to sustain the reproductive capacity that in turn contributes to the high recruitment each year, e.g. the mean biomass of saugers caught in three inch mesh in the north basin is more than an order of magnitude greater than it is in the south basin. In turn, this large fraction of younger biomass contributes to a higher biomass in the 3.75 to 4.25 inch meshes in the north than in the south. These trends are less evident with respect to walleye biomasses caught in various meshes. This is due to walleyes' attaining larger body sizes at faster growth rates.

In the north basin, frequencies of immature saugers caught in small meshes were low and they decreased regularly with increasing mesh size, as expected.

In the channel and south basin, there was no relation of frequencies of immature saugers and mesh sizes because the lower minimum commercial mesh size effectively crops most of the saugers when they attain lengths of 300 to 350 mm. Frequencies of immature walleyes decreased rapidly with increasing mesh size in the north basin as expected but in the south basin, frequencies of immature walleyes increased with increasing mesh size. One possible explanation is that the high frequencies of immature walleyes caught in larger meshes are composed of slower growing fish that are not recruited to commercial meshes until they are relatively old.

Mean lengths and weights of whitefish increased rapidly with increasing mesh size and frequencies of immature whitefish decreased rapidly with increasing mesh size. The distribution of whitefish biomass over a range of meshes was markedly different than that of walleyes and saugers. Mean whitefish biomass mesh^{-1} reached a maximum in the 3.75 inch mesh and rapidly decreased with increasing mesh size. This may be a function of whitefish' being gilled in nets as opposed to walleyes' and saugers' tangling in nets.

Summary

Tables 22 and 23 relate various population parameters of saugers and walleyes to the minimum commercial mesh sizes that are used in the north, channel and south basins of Lake Winnipeg. In general, mean ages, lengths, weights and asymptotic sizes of saugers and walleyes

Table 22. Relationships of minimum mesh sizes and various population parameters of saugers within the three major areas of Lake Winnipeg.

Parameter	Area and mesh size		
	South(3 inch)	Channel(3.75 inch)	North(4.25 inch)
Experimental			
Mean age (years)	4.38	4.99	8.14
Mean length (mm)	293.34	282.17	347.92
Mean weight (gm)	268.95	223.92	496.58
Annual mortality(%)			
Robson-Chapman	87.4	60.0	41.7
Regression	89.1	43.5	31.6
Growth rate			
Exponential	0.387-0.436	0.368	0.287
von Bertalanffy	1.688	0.285	0.285
Asymptotic size(mm)	301	361	402
Slope of length-weight curve	2.544	2.893	3.104
Mean biomass mesh^{-1}(kg)			
3 inch	4.496	1.991	9.733
4.25 inch	1.272	0.306	2.048
Mean frequency of immature fish gang^{-1}	84.53	80.37	11.15
Commercial			
Mean age (years)			
Summer	5.54	5.56	6.13
Fall	4.62	5.32	5.29
Mean length(mm)			
Summer	316.44	299.25	329.45
Fall	304.55	315.98	317.49
Mean weight(gm)			
Summer	407.36	296.66	403.25
Fall	320.06	362.14	421.04
Annual mortality(%)			
Robson-Chapman			
Summer	59.34	78.56	66.38
Fall	93.48	86.33	74.84
Regression			
Summer	44.57	78.78	60.15
Fall	94.97	82.62	79.41

Table 23. Relationships of minimum mesh sizes and various population parameters of walleyes within the northern and southern areas of Lake Winnipeg.

Parameter	Area and mesh size	
	South(3 inch)	North(4.25 inch)
Experimental		
Mean age (years)	4.16	5.35
Mean length (mm)	352.97	352.67
Mean weight (gm)	501.71	544.56
Annual mortality(%)		
Robson-Chapman	72.8	60.2
Regression	69.9	51.8
Growth rate		
Exponential	0.445	0.397
von Bertalanffy	0.326	———
Asymptotic size (mm)	511	———
Slope of length-weight curve	2.685	3.156
Mean biomass mesh^{-1} (kg)		
3 inch	4.416	4.392
4.25 inch	0.634	0.662
Mean frequency of immature fish gang^{-1}	53.28	44.73
Commercial		
Mean age (years)		
Summer	4.64	6.38
Fall	3.78	5.86
Mean length (mm)		
Summer	389.16	425.62
Fall	359.61	427.34
Mean weight (gm)		
Summer	786.53	951.55
Fall	541.92	1036.87
Annual mortality(%)		
Robson-Chapman		
Summer	80.21	82.45
Fall	67.04	66.04
Regression		
Summer	44.57	73.29
Fall	56.83	63.94

increase with increasing mesh sizes. Mortality and growth rates decrease with increasing mesh size. Southern stocks exhibit negatively allometric growth while northern stocks exhibit positively allometric growth. The mean biomass of saugers caught in various meshes is greater in the north basin than in the south basin and mean frequencies of immature recruited fish are lower in the north than in the south. Saugers suffer an extremely high mortality rate in the south basin and their growth rate is probably at its biological maximum in order to compensate for heavy mortality. These trends are less evident in walleye stocks. Long term decreases in mean ages and sizes of commercially caught walleyes and saugers in the south basin indicate that these populations are highly overexploited.

RECOMMENDATIONS

1. This is the first study that has provided a generally comprehensive overview of population characteristics of walleyes and saugers in Lake Winnipeg in relation to fishery effects. In order to comprehensively monitor changes in these population characteristics from year to year, it is strongly suggested that the experimental design be kept constant. Many empirical errors may exist in this study but at least relative changes may be monitored by standardizing the methods and sampling locations used in 1979.
2. Attempts to estimate various parameters of the maturation process and attempts to use these parameters to monitor changes in fishing pressures will be more successful if:
    a. sampling time is closer to the spawning season of walleyes and saugers.

b. fewer workers participate in visual determinations of maturity categories.

c. the "developing" category is eliminated from the maturity classification scheme.

3. Estimates of mean numbers of fish mesh^{-1} and mean biomass mesh^{-1} will be more accurate if the duration of sets is standardized throughout all sampling locations each year.
4. To avoid aberrations in commercial catch curves, it is suggested that catches should be sampled according to the proportions of large, medium and small fish that occur at each sampling station.
5. A long-term analysis of the passage of cohorts through the fishery should be undertaken. Such an analysis would allow refinement of management strategies so that fisheries would crop fish at their critical sizes. Again, this requires data from a standardized experimental design.
6. It is evident that southern Lake Winnipeg populations of walleyes and saugers are suffering from overexploitation of immature fish. Since fishing effort (in terms of numbers of fishermen, net yardages, etc.) cannot be effectively controlled, the only remaining alternative is to increase the legal minimum commercial mesh size in the south basin. Enough data from the north basin exists to choose a mesh size that will protect the immature portions of walleye and sauger stocks from overexploitation.

ACKNOWLEDGMENTS

J. O'Connor, R. Janusz, J. Beyette, J. Patalas, B. Olynyk, B. Govereau, K. Kristofferson and M. Erickson all shared in field activities. H. Thomasson, A. Peterson and P. Daniels contributed to the smooth functioning of the research vessel. L. Koreluik, W. Patterson, P. Zacharias, H. Metheringham and E. Harrington processed scales and otoliths. J. Beyette provided assistance with data storage and retrieval. J. O'Connor and A. J. Derksen prcvided editorial advice. B. Bean typed the manuscript. Sincere appreciation is extended to all participants.

LITERATURE CITED

Abrosov, V. N. 1967. Determination of commercial turnover in natural bodies of water. Problems of Ichthyology. Trans. from Russian by Am. Fish. Soc. 9: 482-489.

Arnason, I. G. 1951. Branchiopoda and Ostracoda of Manitoba. Fish. Res. Board Can., Central Fisheries Station, Winnipeg, 35p.

Bajkov, A. D. 1930. Investigation in connection with the whitefish Coregonus clupeaformis (Mitchill). Ph.D. Thesis, Univ. of Manitoba, Winnipeg, Man., 125p.

Bajkov, A. D. 1933. Report on fisheries investigations in Manitoba. Man. Dept. Mines and Nat. Res. MS Rep. 33-1, 48p.

Bligh, E. G. 1970. Mercury contamination in fish. 20th Ann. Inst. Public Health Inspectors, Winnipeg, Man. Oct. 19-23, 1970: 10-19.

_____. 1972. Mercury in Canadian fish. Can. Inst. Food Sci. Tech. 5: A6-A14.

Davidoff, E. B. 1978. Changes in the population of lake whitefish (Coregonus clupeaformis) in Lake Winnipeg from 1971-1977. Man. Dept. Mines, Nat. Res. and Environ. MS Rep. 78-80, 35p.

Davidoff, E. B., R. W. Rybicki, and K. H. Doan. 1973. Changes in the population of lake whitefish (Coregonus clupeaformis) in Lake Winnipeg from 1944 to 1969. J. Fish. Res. Board Can. 30: 1667-1682.

Doan, K. H. 1959. The 1959 summer whitefish fishery on Lake Winnipeg. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 59-2, 14p.

Evans, D., and J. G. Stockner. 1972. Attached algae on artificial and natural substrates in Lake Winnipeg, Manitoba. J. Fish. Res. Board Can. 29: 31-44.

Grant, H. C. 1938. The commercial fishing industry of Manitoba. Economic Survey Board, Prov. of Manitoba.

Green, R. H. 1971. A multivariate statistical approach to the Hutchinson niche: bivalve molluscs of central Canada. Ecology 52: 543-556.

Green, R. H. 1972. Distribution and morphological variation of Lampsilis radiata (Pelecypoda, Unionidae) in some central Canadian lakes: A multivariate statistical approach. J. Fish. Res. Board Can. 29: 1565-1570.

Hanford, P., G. Bell, and T. Reimchen. 1977. A gillnet fishery considered as an experiment in artificial selection. J. Fish. Res. Board Can. 34: 954-961.

Hewson, L. C. 1951. A description of the Lake Winnipeg commercial fishery. Fish. Res. Board Can. MS Rep. 507, 42p.

Hewson, L. C. 1953. The Lake Winnipeg trap-net experiment with returns of tagged fish as an appendix. Fish. Res. Board Can. MS Rep. Biol. Ser. 558, 11p.

Hewson, L. C. 1957. Exploratory fishing in Lake Winnipeg with gill nets of graded mesh size. Fish Res. Board Can. MS Rep. 626, 13p.

Hewson, L. C. 1959a. A seven-year study of the fishery for lake whitefish, Coregonus clupeaformis, on Lake Winnipeg. J. Fish. Res. Board Can. 16: 107-120.

Hewson, L. C. 1959b. A study of six winter seasons of commercial fishing on Lake Winnipeg, 1950-1955. J. Fish. Res. Board Can. 16: 131-145.

Hewson, L. C. 1960. A history of the Lake Winnipeg fishery for whitefish, Coregonus clupeaformis, with some reference to its economics. J. Fish. Res. Board Can. 17: 625-639.

Hinks, D. 1943. The Fishes of Manitoba. Man. Dept. Mines and Nat. Res., 102p.

Howard, W. 1974. Summer, fall and winter whitefish data, Lake Winnipeg, 1964 to 1967. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 74-5, 21p.

Keleher, J. J. 1952. Growth and Triaenophorus parasitism in relation to taxonomy of Lake Winnipeg ciscoes (Leucichthys). J. Fish. Res. Board Can. 8: 469-478.

Keleher, J. J., and B. Kooyman. 1957. Supplement to Hinks, "The Fishes of Manitoba". Man. Dept. Mines and Nat. Res. MS Rep. 57-4, 117p.

Kennedy, W. A. 1951. The bearing of the Great Slave Lake and the Lake Winnipeg studies on the Triaenophorus problem. Fish. Res. Board Can. MS Rep. 516, 5p.

Kennedy, W. A. 1954. Tagging returns, age studies and fluctuations in abundance of Lake Winnipeg whitefish, 1931-1951. J. Fish. Res. Board Can. 11: 284-309.

Kenny, A. R. 1972. Total mercury and methylmercury in fish organs. Fish. Res. Board Can. MS Rep. 1167: 40-45.

Kooyman, B. 1952. Pickeral-sauger investigation, Lake Winnipeg fall season, Sept. 16 - Oct. 20. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 52-5, 19p.

Kooyman, B. 1955. Lake Winnipeg mesh size for whitefish, summer 1954-55. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 55-5, 9p.

Kristofferson, A. H., D. R. Toews and A. J. Derksen. 1975. Limnological study of the north basin of Lake Winnipeg, 1974. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 75-5, 54p.

Kushner, D. W. 1971. Sediments in the south basin of Lake Winnipeg. M.Sc. Thesis, Univ. of Manitoba, Winnipeg, Manitoba. 92p.

Neave, F. 1932. A study of the mayflies (Hexagenia) of Lake Winnipeg. Contrib. Can. Biol. Fish. 7: 177-201.

Reinke, E., J. F. Uthe and D. Jamieson. 1972. Organochlorine pesticide residues in commercially caught fish in Canada - 1970. Pestic. Monit. J. 6: 43-49.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fish. Soc. 90: 181-189.

Rybicki, R. W. 1961. Analysis of Lake Winnipeg whitefish tag returns 1959-1960. Man. Dept. Mines, Nat. Res. and Environ. Mgmt. MS Rep. 61-5, 7p.

Rybicki, R. W. 1062. Pickerel tag returns, Lake Winnipeg, 1959-1962. Man. Dept. Mines, Nat. Res. and Environ. Mgmt. MS Rep. 62-3, 14p.

Rybicki, R. W., and K. H. Doan. 1966. Changes in the Lake Winnipeg whitefish population from 1944 to 1964. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 66-4, 20p.

Scott, D. P., and F. A. J. Armstrong. 1972. Mercury concentration in relation to size in several species of freshwater fishes from Manitoba and northwestern Ontario. J. Fish. Res. Board Can. 29: 1685-1690.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. 6th Ed. Iowa State Univ. Press, Ames, Iowa. 593p.

Appendix A
Species composition and abundances of gillnetted fish

Table A1. Lake Winnipeg fish species composition, summer 1979. Numbers are numbers of fish caught at each location.

Location	Gang no.	Species						
		walleye	sauger	whitefish	perch	burbot	tullibee	pike
North end								
Sturgeon Bay	1,2	87	210	202	114	3	20	4
Reindeer Is.	3,4	49	69	132	0	14	105	0
Poplar Reefs	5,6	13	380	99	0	80	248	0
Spider Is.	7	2	29	62	6	5	19	12
Mossy Ranges	8	10	45	47	1	4	7	0
Warren's Landing	9	15	98	87	1	3	83	17
"Deep"	10	5	22	35	0	5	19	0
Inshore Gaps	11	49	10	73	2	2	109	2
Grand Rapids*	12,13	99	38	117	-	-	-	-
Gull Bay	14,15	49	4	107	19	3	98	21
Big Black R.	16,17	1	74	357	26	29	215	2
Berens R.	18	1	70	133	2	53	86	0
Total		281	1011	1334	171	201	1009	58
Channel								
Grindstone	19,20	4	45	3	3	44	46	0
Fisher Bay	21,22	12	58	0	47	4	14	1
Bloodvein Bay	23,24	16	20	0	45	2	9	0
Catfish Creek	25,26	21	86	11	2	262	761	0
Total		53	209	14	97	312	830	1
South end								
Gimli	27,28	292	278	0	2	2	334	30
Camp Morton	29	15	23	0	1	1	51	3
Drunken Pt.	30	33	36	1	0	0	68	0
Elk Is.	31	67	71	3	12	9	28	3
Ironwood Pt.	32	22	28	0	0	1	24	2
Winnipeg Beach*	33	30	19	-	-	-	-	-
Balsam Bay*	34	47	63	-	-	-	-	-
Grand Marais*	35	22	28	-	-	-	-	-
Deer Is.	36	29	87	3	1	0	38	2
Observation Pt.	37	53	18	6	0	0	115	2
Sandy R.	38	49	9	3	0	0	37	1
Total		560	550	16	16	13	695	43

*Incomplete data sets were not used in the calculations

Table A1 continued

longnose sucker	white sucker	northern redhorse sucker	bass	catfish and bullheads	drum	carp	goldeye	mooneye
85	51	0	0	0	0	0	0	0
33	5	0	0	0	0	0	0	0
10	7	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0
-	-	-	-	-	-	-	-	-
14	49	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
176	116	0	0	0	0	0	0	0
4	10	0	0	0	85	0	0	0
3	29	0	1	0	58	1	0	0
8	158	1	0	2	148	0	6	6
22	3	0	0	0	90	1	0	0
37	200	1	1	2	381	2	6	6
0	2	0	1	2	2	0	49	0
1	0	0	0	1	0	0	2	0
0	0	0	0	0	0	0	26	0
0	0	0	1	2	6	1	27	0
-	-	-	0	1	1	0	11	0
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0	0	0	0	0	17	0	1	0
0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	1	0
1	2	0	2	6	26	2	118	0

Appendix B
Comparison of scale ages and otolith ages

Table B1. Comparison of scale ages and mean otolith ages of saugers from the three major areas of Lake Winnipeg.

Area	Scale age (years)	Mean otolith age (years)	95% C.I.	Sample size
South	2	2.80	1.76,3.84	5
	3	3.96	3.63,4.29	25
	4	5.08	4.83,5.34	93
	5	5.70	5.51,5.89	89
	6	8.58	7.24,9.92	12
	7	6	-	1
	8	8	-	1
Channel	2	5	-	1
	3	4.24	3.89,4.58	17
	4	5.48	5.20,5.76	46
	5	6.23	5.97,6.49	77
	6	7.23	6.77,7.49	26
	7	8.70	7.70,9.70	20
	8	8.71	8.02,9.41	7
	9	13	-	1
	10	12	-	1
North	4	6	-	2
	5	7.89	6.73,9.04	18
	6	8.71	7.94,9.48	31
	7	10.12	9.40,10.85	41
	8	10.43	9.77,11.09	37
	9	12.36	11.01,13.71	14
	10	13.62	11.71,15.52	13
	11	14.71	12.23,17.20	7
	12	14.67	11.84,17.50	3
	13	16.50	-	2
	14	20	-	1

Appendix C
Mesh size effects

Table C1. North basin walleye mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.75	4.25	5	5.25
number	183	88	69	12	5	0
no. immature	162	72	42	2	1	
% immature	89.01	81.82	60.87	16.67	20.00	
mean length (mm)	332.19	350.16	390.62	431.17	430.00	
mean weight (gm)	434.34	528.64	741.30	992.50	1120.00	
Age (years)	Frequency (%)					
3	1.65	2.27				
4	35.71	23.86	5.8			
5	37.36	38.64	24.64	16.67	20	
6	17.58	20.45	31.88	8.33	20	
7	5.49	10.23	33.33	25.00	40	
8	1.65	4.55	4.35	33.33	20	
9	0.55			16.67		
Mean biomass mesh^{-1} (kg)	4.392	2.584	2.842	0.662	0.311	
Mean no. mesh^{-1}	10.1	4.89	3.83	0.67	0.28	

Table C2. South basin walleye mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.5	3.75	4	4.25
number	241	224	119	51	38	27
no. immature	85	97	62	34	24	16
% immature	35.27	43.3	52.1	66.6	63.16	59.26
mean length (mm)	343.7	355.59	360.87	364.37	366.45	320.26
mean weight (gm)	439.79	473.68	556.55	641.57	582.95	563.85
Age(years)	Frequency (%)					
1	0.41			3.92	2.63	3.7
2	2.07	0.45	6.72	11.76	15.79	33.33
3	22.41	25.45	9.24	21.57	13.16	18.52
4	45.23	36.16	39.50	21.57	21.05	7.41
5	24.48	27.73	32.77	29.41	28.95	7.41
6	4.98	8.48	10.08	9.8	15.79	18.52
7	0.41	2.23	0.84	1.96	2.63	3.7
8			0.84			3.7
9						3.7
Mean biomass mesh^{-1} (kg)	4.416	4.421	2.760	1.363	0.923	0.634
Mean no. fish mesh^{-1}	20.08	18.67	9.92	4.25	3.17	2.25

Table C3. North basin sauger mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.75	4.25	5	5.25
number	424	367	205	43	8	7
no. immature	29	13	6	0	2	2
% immature	6.84	3.54	2.93	0	25	28.57
mean length (mm)	331.78	340.9	380.02	405.91	374.75	365
mean weight (gm)	414.88	453.19	655.8	857.21	767.5	702.86
Age (years)	Frequency (%)					
4		1.09	0.98		12.5	14.3
5	6.84	2.72				14.3
6	21.46	11.44	9.76		12.5	
7	22.41	24.8	16.1	11.63	12.5	
8	23.82	26.16	24.88	20.93		
9	14.62	16.08	23.9	20.93		
10	3.54	6.27	11.71	9.3	12.5	14.3
11	3.07	4.36	5.37	9.3	12.5	14.3
12	1.65	1.91	3.41	4.65	12.5	14.3
13	0.71	2.45	1.46	4.65		14.3
14	1.18	1.91	1.46	4.65	12.5	
15	0.71	0.81	0.98	13.97		14.3
mean biomass mesh^{-1} (kg)	9.773	9.240	7.469	2.048	0.341	0.273
mean no. fish mesh^{-1}	23.56	20.39	11.39	2.39	0.45	0.39

Table C4. Channel sauger mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.75	4.25	5	5.25
number	59	38	36	14	29	28
no. immature	31	31	30	11	25	28
% immature	52.54	81.58	83.34	78.57	86.21	100
mean length (mm)	300.8	281.5	276.64	258.93	270.69	276.04
mean weight (gm)	270	225.26	208.89	175	192.76	204.64
Age (years)	Frequency (%)					
2	1.69			7.14		
3	3.39	18.42	2.78	35.71	13.79	3.57
4	22.03	13.16	36.11	7.14	31.03	28.57
5	28.81	42.11	38.89	35.71	34.48	53.57
6	20.34	7.89	11.11	7.14	13.79	14.29
7	16.95	7.89	8.33	7.14	6.9	
8	3.39	10.53	2.78			
9	1.69					
10	1.69					
Mean biomass $mesh^{-1}$ (kg)	1.991	1.070	0.940	0.306	0.699	0.716
Mean no. fish $mesh^{-1}$	7.38	4.75	4.5	1.75	3.63	3.63

Table C5. South basin sauger mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.5	3.75	4	4.25
number	178	99	106	134	88	61
no. immature & developing	160	91	90	112	76	43
% immature & developing	89.89	91.92	84.91	83.58	86.36	70.49
mean length (mm)	305.1	299.76	289.26	286.25	285.69	286.75
mean weight (mm)	303.12	289.8	251.56	248.45	246.83	250.18
Age (years)	Frequency (%)					
2	1.69	2.02	1.89	2.24	2.27	3.28
3	8.43	9.09	11.32	13.43	10.23	9.84
4	39.89	33.33	49.06	44.78	38.64	39.34
5	42.13	46.46	34.91	35.07	43.18	40.48
6	6.74	8.01	2.83	4.48	5.68	6.56
7	1.12					
8		1.01				
Mean biomass mesh^{-1} (kg)	4.496	2.391	2.222	2.774	1.810	1.272
Mean no. fish mesh^{-1}	14.83	8.25	8.83	11.17	7.34	5.08

Table C6. North basin whitefish mesh size effects.

Parameter	Mesh size (inches)					
	3	3.25	3.75	4.25	5	5.25
number	109	181	514	376	193	65
no. immature	50	78	158	105		
% immature	45.87	43.09	30.74	27.93		
mean length (mm)	335.83	352.31	374.16	378.8	409.68	431.89
mean weight (gm)	561.01	644.25	778.7	858.67	1055.54	1323.85
Age (years)	Frequency (%)					
2		0.55				
3	10.09	6.08	0.39	0.27		
4	48.62	29.83	18.68	10.64	3.63	1.54
5	23.85	37.02	44.75	42.55	29.53	15.38
6	14.68	21.55	26.65	31.38	41.45	20
7	2.75	4.42	7.2	11.7	16.58	26.15
8		0.55	2.14	3.19	7.25	16.92
9				0.27	0.52	13.85
10					0.52	1.54
11			0.19			4.62
12						
13						
14					0.52	
Mean biomass mesh^{-1} (kg)	3.397	6.478	22.236	17.937	11.318	4.781
Mean no. fish mesh^{-1}	6.06	10.06	28.56	20.89	10.72	3.61